3. PEDESTRIAN MODE

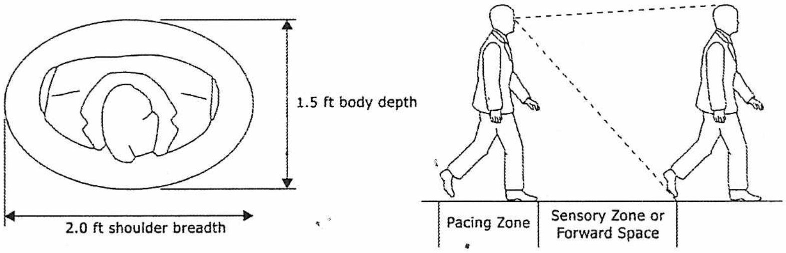
PEDESTRIAN CHARACTERISTICS

Pedestrian Space Requirements

Pedestrian facility designers use body depth and shoulder breadth for minimum space standards, at least implicitly. A simplified body ellipse of 1.5 ft by 2 ft, with a total area of 3 ft², is used as the basic space for a single pedestrian, as shown in Exhibit 4-11(a). This represents the practical minimum for standing pedestrians. In evaluating a pedestrian facility, an area of 8 ft² is used as the buffer zone for each pedestrian.

A walking pedestrian requires a certain amount of forward space. This forward space is a critical dimension, since it determines the speed of the trip and the number of pedestrians able to pass a point in a given time period. The forward space in Exhibit 4-11(b) is categorized into a pacing zone and a sensory zone (*8*).

Exhibit 4-11
Pedestrian Body Ellipse for Standing Areas and Pedestrian Walking Space Requirement



(a) Pedestrian Body Ellipse (b) Pedestrian Walking Space Requirement

Source: Adapted from Fruin (*8*).

Walking Speed

Factors affecting walking speed.

Pedestrian walking speed is highly dependent on the characteristics of the walking population. The proportion of elderly pedestrians (65 years old or more) and children in the population, as well as trip purpose, affect walking speed. In a national study (*9*), the average walking speed of younger (age 13–60) pedestrians crossing streets was found to be significantly different from that of older pedestrians (4.74 ft/s versus 4.25 ft/s, respectively). The 15th percentile speed, the speed used in the *Manual on Uniform Traffic Control Devices* (*10*) for timing the pedestrian clearance interval at traffic signals, was 3.03 ft/s for older pedestrians and 3.77 ft/s for younger pedestrians. Exhibit 4-12 shows these relationships.

For flow analysis, a default free-flow speed (i.e., an average pedestrian's speed on an otherwise empty sidewalk) of 5.0 ft/s (*11*) is appropriate for sidewalks and walkways, on the basis of average walking speeds. In calculating pedestrian crossing times, the 15th percentile crossing speed should be used. If no more than 20% of pedestrians are elderly, a crossing speed of 3.5 ft/s should be used (*11*). If elderly people constitute more than 20% of the total pedestrians, a crossing speed of 3.0 ft/s should be used. Several other factors may reduce

average pedestrian speed, such as grades over 5% or a high percentage of slow-walking children, and should be taken into consideration.

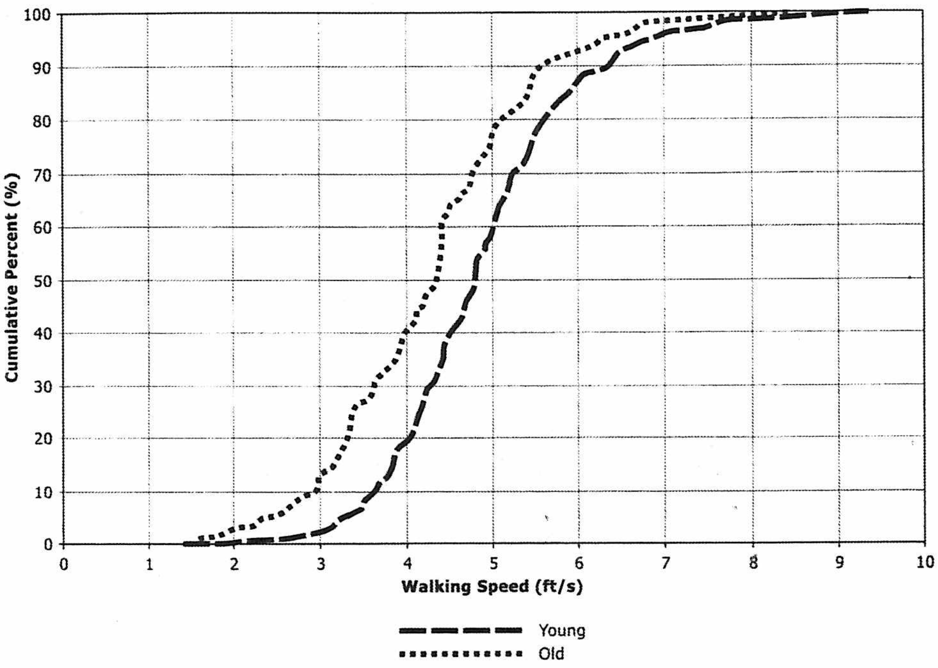


Exhibit 4-12
Observed Older and Younger Pedestrian Walking Speed Distribution at Unsignalized Intersections

Source: Adapted from *TCRP Report 112/NCHRP Report 562* (*9*).

Pedestrian Start-Up Time

At crosswalks located at signalized intersections, pedestrians may not step off the curb immediately when the WALK indication appears, in part because of perception–reaction time and in part to make sure that no vehicles have, or are about to, move into the crosswalk area. A pedestrian start-up time of 3 s is a reasonable midrange value to use for evaluating crosswalks at traffic signals.

PEDESTRIAN FLOW PARAMETERS

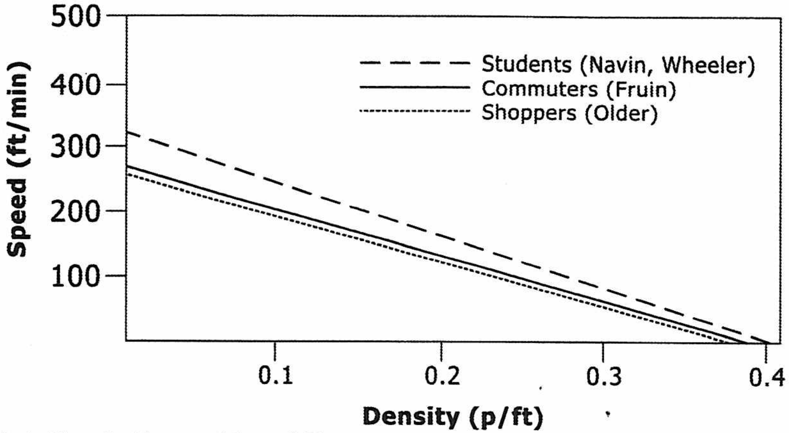
Speed, Flow, and Density Relationships

Speed–Density Relationships

The fundamental relationship between speed, density, and volume for directional pedestrian flow on facilities with no cross-flows, where pedestrians are constrained to a fixed walkway width (because of walls or other barriers), is analogous to that for vehicular flow. As volume and density increase, pedestrian speed declines. As density increases and pedestrian space decreases, the degree of mobility afforded to the individual pedestrian declines, as does the average speed of the pedestrian stream.

Exhibit 4-13 shows the relationship between speed and density for three pedestrian classes.

Exhibit 4-13
Relationships Between Pedestrian Speed and Density



Source: Adapted from Pushkarev and Zupan (*12*).

Flow–Density Relationships

Similarities of pedestrian movement to vehicular traffic.

The relationship among density, speed, and directional flow for pedestrians is similar to that for vehicular traffic streams and is expressed in Equation 4-11:

Equation 4-11

$$v_{ped} = S_{ped} \times D_{ped}$$

where

v_{ped} = unit flow rate (p/min/ft),

S_{ped} = pedestrian speed (ft/min), and

D_{ped} = pedestrian density (p/ft^2).

The flow variable in Equation 4-11 is the unit width flow, defined earlier. An alternative, more useful, expression uses the reciprocal of density, or *space*:

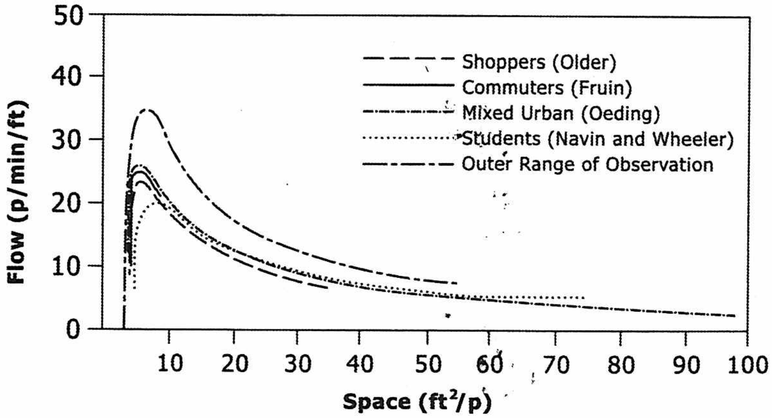
Equation 4-12

$$v_{ped} = \frac{S_{ped}}{M}$$

where M = pedestrian space (ft^2/p).

The basic relationship between flow and space, recorded by several researchers, is illustrated in Exhibit 4-14:

Exhibit 4-14
Relationships Between Pedestrian Flow and Space



Source: Adapted from Pushkarev and Zupan (*12*).

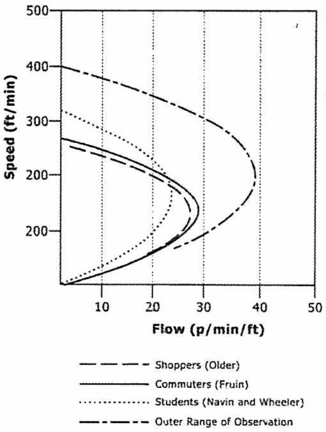
The conditions at maximum flow represent the capacity of the walkway facility. From Exhibit 4-14, it is apparent that all observations of maximum unit flow fall within a narrow range of density, with the average space per pedestrian varying between 5 and 9 ft^2/p. Even the outer range of these observations indicates that maximum flow occurs at this density, although the actual flow in this study is considerably higher than in the others. As space is reduced to less than 5 ft^2/p, the flow rate declines precipitously. All movement effectively stops at the minimum space allocation of 2 to 4 ft^2/p.

These relationships show that pedestrian traffic can be evaluated qualitatively by using basic concepts similar to those of vehicular traffic analysis. At flows near capacity, an average of 5 to 9 ft^2/p is required for each moving pedestrian. However, at this level of flow, the limited area available restricts pedestrian speed and freedom to maneuver.

Speed–Flow Relationships

Exhibit 4-15 illustrates the relationship between pedestrian speed and flow. These curves, similar to vehicle flow curves, show that when there are few pedestrians on a walkway (i.e., low flow levels), there is space available to choose higher walking speeds. As flow increases, speeds decline because of closer interactions among pedestrians. When a critical level of crowding occurs, movement becomes more difficult, and both flow and speed decline.

Exhibit 4-15
Relationships Between Pedestrian Speed and Flow

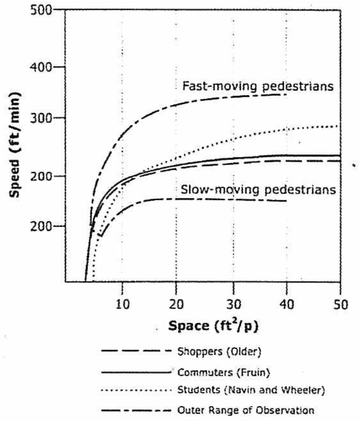


Source: Adapted from Pushkarev and Zupan (*12*).

Speed–Space Relationships

Exhibit 4-16 also confirms the relationships of walking speed and available space. The outer range of observations shown in Exhibit 4-16 indicates that at an average space of less than 15 ft^2/p, even the slowest pedestrians cannot achieve their desired walking speeds. Faster pedestrians, who walk at speeds of up to 350 ft/min, are not able to achieve that speed unless the average space is 40 ft^2/p or more.

Exhibit 4-16
Relationships Between Pedestrian Speed and Space



Source: Adapted from Pushkarev and Zupan (*12*).

Flow on Urban Sidewalks and Walkways

While the fundamental relationships described above hold for pedestrians on constrained facilities with linear flow (e.g., bridges and underground passageways), they are complicated on urban sidewalks and walkways by other factors. In particular, cross-flows, stationary pedestrians, and the potential for spillover outside of the walkway affect pedestrian flows on these facilities. Quantitative research describing the effects of these factors on pedestrian flow is limited, but the effects are described qualitatively here.

Cross-flows of pedestrians entering or exiting adjacent businesses, getting on or off buses at bus stops, or accessing street furniture are typical on most urban pedestrian facilities. Where pedestrian volumes are high, these cross-flows will disrupt the speed–flow relationships described above, resulting in lower pedestrian speeds at equivalent flow rates. In addition to cross-flows, stationary pedestrians will be present on most urban pedestrian facilities, as pedestrians stop to talk, look in store windows, or pick up a newspaper from a vending machine. Stationary pedestrians reduce pedestrian flow by requiring pedestrians to maneuver around them and decreasing the available width of the walkway.

Finally, in situations where pedestrians are not physically confined within the walkway, pedestrians will often choose to walk outside of the prescribed walking area (e.g., walk in the furniture zone or street) when high densities are reached. Thus, in practice, facilities will often break down, with pedestrians spilling over into the street, before the maximum flow rate shown in Exhibit 4-14 is reached. Therefore, typical practice is to design pedestrian facilities for LOS C or D densities (*13*).

The result of the combination of factors described above is that many pedestrian facilities will reach effective failure at densities far less than the facility's capacity. Analysis of pedestrian facilities should take into consideration local conditions, including the presence of destinations along the facility that contribute to cross-flows and stationary pedestrians, as well as opportunities for pedestrians to spill over onto adjacent facilities.

Pedestrian Type and Trip Purpose

The analysis of pedestrian flow is generally based on the mean, or average, walking speeds of groups of pedestrians. Within any group, or among groups, there can be considerable differences in flow characteristics due to trip purpose, adjacent land use, type of group, age, mobility, cognitive ability, and other factors.

Pedestrians going to and from work and using the same facilities day after day walk at higher speeds than do shoppers, as was shown in Exhibit 4-13. Older or very young persons tend to walk more slowly than do other groups. Shoppers not only tend to walk more slowly than do commuters but also can decrease the effective walkway width by stopping to window-shop and by carrying shopping bags. The analyst should adjust for pedestrian behavior that deviates from the regular patterns represented in the basic speed, volume, and density curves.

Influences of Pedestrians on Each Other

Photographic studies show that pedestrian movement on sidewalks is affected by other pedestrians, even when space is more than 40 ft²/p. At 60 ft²/p, pedestrians have been observed walking in a checkerboard pattern, rather than directly behind or alongside each other. The same observations suggest the necessity of up to 100 ft²/p before completely free movement occurs without conflicts, and that at 130 ft²/p, individual pedestrians are no longer influenced by others (*14*). Bunching or platooning does not disappear until space is about 500 ft²/p or higher.

Maintaining flow in the minor (opposing) direction.

Another issue is the ability to maintain flow in the minor direction on a sidewalk when opposed by a major pedestrian flow. For pedestrian streams of roughly equal flow in each direction, there is little reduction in the capacity of the walkway compared with one-way flow, because the directional streams tend to separate and occupy a proportional share of the walkway. However, if the directional split is 90% versus 10% and space is 10 ft²/p, capacity reductions of about 15% have been observed. This reduction results from the minor flow using more than its proportionate share of the walkway.

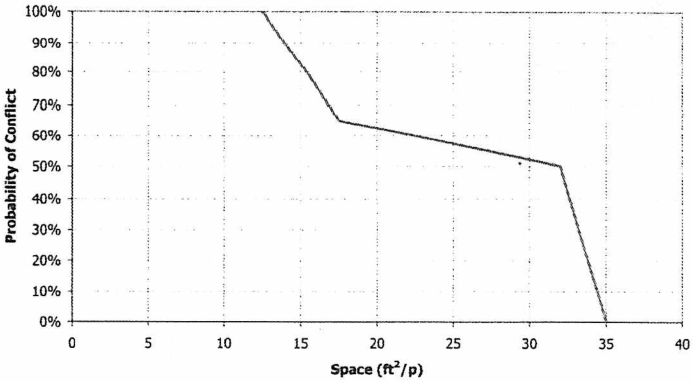
Opposing flows on stairways.

Similar, but more severe, effects are seen with stairways. In contrast to their behavior on a level surface, people tend to walk in lines or lanes in traversing stairs. A small reverse flow occupies one pedestrian lane (30 in.) of the stair's width. For a stair 60 in. (5 ft) wide, a small reverse flow could consume half its capacity (*13*).

Cross-flows.

A pedestrian's ability to cross a pedestrian stream is impaired at space values less than 35 to 40 ft²/p, as shown in Exhibit 4-17 (*8*). Above that level, the probability of stopping or breaking the normal walking gait is reduced to zero. Below 15 ft²/p, virtually every crossing movement encounters a conflict. Similarly, the ability to pass slower pedestrians is unimpaired above 35 ft²/p, but it becomes progressively more difficult as space allocations drop to 18 ft²/p, the point at which passing becomes virtually impossible.

Exhibit 4-17
Probability of Conflict Within Pedestrian Cross-Flows



Source: Adapted from Fruin (8).

Pedestrian Facility Characteristics

Effective Walkway Width

The lane concept used for highway analysis is frequently not applicable to pedestrian analysis, because studies have shown that pedestrians normally do not walk in organized lanes. The concept is meaningful, however, in the following situations:

- Determining how many pedestrians can walk abreast in a given walkway width—for example, in establishing the minimum sidewalk width that will permit two pedestrians to pass each other conveniently; and
- Determining the capacity of a stairway, since pedestrians will tend to organize into lanes on stairways.

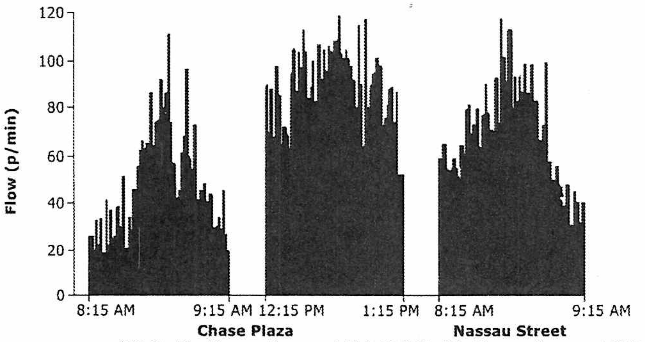
In other situations, the capacity of a pedestrian facility is directly related to the width of the facility. However, not all of the facility's width may be usable, because of obstructions and pedestrians' tendencies to shy away from curbs and building walls. The portion of a pedestrian facility's width that is used for pedestrian circulation is called the *effective width*. The degree to which single obstructions, such as poles, signs, and hydrants, influence pedestrian movement and reduce effective walkway width is not extensively documented. Although a single point of obstruction would not reduce the effective width of an entire walkway, it would affect its immediate vicinity.

To avoid interference when two pedestrians pass each other, each should have at least 2.5 ft of walkway width (*12*). When pedestrians who know each other walk close together, each occupies an average width of 26 in., allowing considerable likelihood of contact due to body sway. Lateral spacing less than this occurs only in the most crowded situations.

Pedestrian Platoons

Average pedestrian flow rates are of limited usefulness unless reasonable time intervals are specified. Exhibit 4-18 illustrates that average flow rates can be misleading. The data shown are for two locations in New York City, but the pattern is generally characteristic of concentrated central business districts. Flows during a 1-min interval can be more than double the rate in another, particularly at relatively low flows. Even during the peak 15-min periods, the peak 1-min flow exceeded the average flow by at least 20% and sometimes up to 75%.

Exhibit 4-18
Minute-by-Minute Variations in Pedestrian Flow



Source: Adapted from Pushkarev and Zupan (*12*).

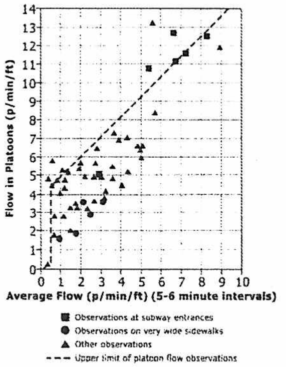
Depending on traffic patterns, a facility designed for average flow can afford a lower quality of flow for a portion of its pedestrian traffic. However, it is not prudent to design for extreme peak 1-min flows that occur only 1% or 2% of the time. A relevant time period should be determined through closer evaluation of the short-term fluctuations of pedestrian flow.

Short-term fluctuations are present in most unregulated pedestrian traffic flows because of the random arrivals of pedestrians. On sidewalks, these random fluctuations are exaggerated by the interruption of flow and queue formation caused by traffic signals. Transit facilities can create added surges in demand by releasing large groups of pedestrians in short time intervals, followed by intervals during which no flow occurs. Until they disperse, pedestrians in these types of groups move together as a platoon (Exhibit 4-19). Platoons can also form when passing is impeded because of insufficient space and faster pedestrians must slow down behind slower-moving ones.

Exhibit 4-19
Platoon Flow on a Sidewalk

The scatter diagram shown in Exhibit 4-20 compares the platoon flow rate (i.e., the rate of flow within platoons of pedestrians) with the average flow rate for durations of 5 to 6 min. The dashed line approximates the upper limit of platoon flow observations.

Exhibit 4-20
Relationship Between Platoon Flow and Average Flow



Source: Adapted from Pushkarev and Zupan (*12*).

CAPACITY CONCEPTS

Pedestrian Circulation Facilities

Pedestrian capacity on facilities designed for pedestrian circulation is typically expressed in terms of *space* (square feet per pedestrian) or *unit flow* (pedestrians per minute per foot of walkway width). The relationship between space and flow was illustrated in Exhibit 4-14. Capacity occurs when the maximum flow rate is achieved. Typical values for pedestrian circulation facilities are as follows:

- Walkways with random flow, 23 p/min/ft;
- Walkways with platoon flow (average over 5 min), 18 p/min/ft;
- Cross-flow areas, 23 p/min/ft (sum of both flows); and
- Stairways (up direction), 15 p/min/ft.

As shown in Exhibit 4-15, average pedestrian speeds at capacity are about half the average speed obtained under less congested conditions. As a result, pedestrian circulation facilities are typically not designed for capacity but rather for a less congested condition that achieves lower pedestrian throughput but that provides pedestrians with greater opportunity to travel at their desired speed with minimal conflicts with other pedestrians. Moreover, as described above under "Flow on Urban Sidewalks and Walkways," pedestrian facilities often break down before maximum flow rates are achieved, as a result of pedestrian spillover outside of the walkway into the furniture zone or roadway.

Pedestrian Queuing Facilities

Pedestrian capacity on facilities designed for pedestrian queuing is expressed in terms of space (square feet per pedestrian). In a queuing area, the pedestrian stands temporarily while waiting to be served. In dense, standing crowds, there is little room to move, but limited circulation is possible as the average space per pedestrian increases. Queuing at or near capacity (2 to 3 ft^2/p) typically occurs only in the most crowded elevators or transit vehicles. Queuing on sidewalks, waiting to cross at street corners, is more typically in the 3 to 6 ft^2/p range, which is still crowded but provides some internal maneuverability.

4. BICYCLE MODE

BICYCLE FLOW PARAMETERS

Although bicyclists are not as regimented as vehicles, they tend to operate in distinct lanes of varying widths when space is available. The capacity of a bicycle facility depends on the number of effective lanes used by bicycles. Shared-lane facilities typically have only one effective lane, but segregated facilities such as bicycle lanes, shoulder bikeways, pathways, and cycle tracks may have more than one effective lane, depending on their width. When possible, an analysis of a facility should include a field evaluation of the number of effective lanes in use. When this is not possible, or when future facilities are planned, a standard width for an effective bicycle lane is approximately 4 ft (*15*). The American Association of State Highway and Transportation Officials recommends that off-street bicycle paths be 10 ft wide (*15*).

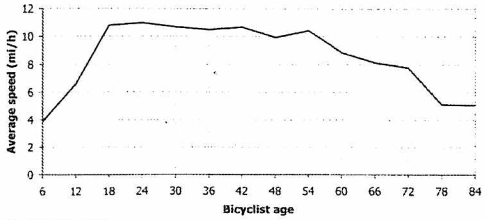
Research demonstrates that three-lane bicycle facilities operate more efficiently than two-lane bicycle facilities, affording considerably better quality of service to users (*16*). The improved efficiency is due primarily to increased opportunities for passing and for maneuvering around other bicyclists and pedestrians. This reinforces the value of determining the number of effective lanes as the principal input for analyzing a bicycle facility.

A study that compared mean bicycle speeds with bicycle flow rates over 5-min periods found at most a minor effect of flow rates on speed, for flow rates ranging from 50 to 1,500 bicycles/h. When the analysis focused on platoons of bicycles with headways less than 5 s, bicycle speeds trended slightly lower as flow rates increased (*17*).

Most bicyclists travel on facilities that are shared with automobiles. In these circumstances, bicycle flow is significantly affected by the characteristics of surrounding automobile flow. Bicyclists often must wait behind queues of automobiles. Even where bicyclists may pass such queues, they are often forced to slow because the available space in which to pass is too constrained to allow free-flow speeds to occur.

Data collected for more than 400 adult bicyclists riding on uninterrupted multiuse segments showed an average speed of 12.8 mi/h (*16*). However, the speed of an individual bicyclist varies considerably from this average on the basis of trail conditions, age, fitness level, and other factors. Exhibit 4-21 shows how bicyclist speed varies with age, on the basis of Danish data. Data are for typical bicyclists on flat terrain.

Exhibit 4-21
Age Effects on Bicyclist Speed



Source: Danish Road Directorate (*18*).

Flow rates of bicyclists usually vary over the course of an hour. As described above for automobiles, HCM analyses typically consider the peak 15 min of flow during the analysis hour. Because inputs to HCM procedures are typically expressed in terms of hourly demands, the HCM uses the PHF, shown by Equation 4-1, to convert an hourly volume into a peak 15-min flow rate. Data for bicycles on eight trails, recorded over three separate time periods for each trail, showed PHFs ranging from 0.70 to 0.99, with an average of 0.85 (*16*).

CAPACITY CONCEPTS

Because service quality deteriorates at flow levels well below capacity, the concept of capacity has little utility in the design and analysis of bicycle paths and other facilities. Capacity is rarely observed on bicycle facilities. Values for capacity, therefore, reflect sparse data, generally from Europe and generally extrapolated from flow rates over time periods substantially less than 1 h.

One study reported capacity values of 1,600 bicycles/h/ln for two-way bicycle facilities and 3,200 bicycles/h/ln for one-way facilities. Both values were for exclusive bicycle facilities operating under uninterrupted-flow conditions (*19*). Other studies have reported values in the range of 1,500 to 5,000 bicycles/h/ln for one-way uninterrupted-flow facilities (*16*).

Danish guidelines suggest that bicycle capacity is normally only relevant at signalized intersections in cities and that a rule of thumb for the capacity of a two-lane cycle track is 2,000 bicycles/h under interrupted-flow conditions (i.e., 1,000 bicycles/h/ln) (*20*). The HCM recommends a saturation flow rate of 2,000 bicycles/h/ln for a one-direction bicycle lane under interrupted-flow conditions, which is equivalent to a capacity of 1,000 bicycles/h/ln when the bicycle lane receives a green indication during 50% of the signal cycle.

DELAY

Delay is an important performance measure for bicyclists on interrupted-flow system elements. This is true because delay increases travel time and because the physical exertion required to accelerate a bicycle makes stopping or slowing undesirable and tiring. The difficulty involved in stopping and starting a bicycle often makes it appropriate to assess not only the control delay incurred by bicyclists but also the number of stops that bicyclists are required to make to traverse a facility. For instance, a facility with STOP signs every several hundred feet will require bicyclists to stop frequently and thus will provide lower capacity and quality of service to users.

Equation 17-21

$$P_F = \left(1 + e^{3.8044 - 0.253 H_{seg} + 0.3434 P_{LTL,seg}}\right)^{-1}$$

where

$I_{a,seg}$ = automobile traveler perception score for segment;

P_{BCDEF} = probability that an individual will respond with a rating of B, C, D, E, or F;

P_{CDEF} = probability that an individual will respond with a rating of C, D, E, or F;

P_{DEF} = probability that an individual will respond with a rating of D, E, or F;

P_{EF} = probability that an individual will respond with a rating of E or F;

P_F = probability that an individual will respond with a rating of F; and

$P_{LTL,seg}$ = proportion of intersections with a left-turn lane (or bay) on the segment (decimal).

Other variables are as previously defined. The derivation of Equation 17-16 is based on the assignment of scores to each letter rating, in which a score of "1" is assigned to the rating of A (denoting "best"), "2" is assigned to B, and so on. The survey results were used to calibrate a set of models that collectively predicts the probability that a traveler will assign various rating combinations for a specified spatial stop rate and proportion of intersections with left-turn lanes. The score obtained from Equation 17-16 represents the expected (or long-run average) score for the population of travelers.

The proportion of intersections with left-turn lanes equals the number of left-turn lanes (or bays) encountered while driving along the segment divided by the number of intersections encountered. The signalized boundary intersection is counted (if it exists). All unsignalized intersections of public roads are counted. Private driveway intersections are not counted, unless they are signal controlled.

The score obtained from Equation 17-16 provides a useful indication of performance from the perspective of the traveler. Scores of 2.0 or less indicate the best perceived service, and values in excess of 5.0 indicate the worst perceived service. Although this score is closely tied to the concept of service quality, it is *not* used to determine LOS for the urban street segment.

PEDESTRIAN MODE

This subsection describes the methodology for evaluating the performance of an urban street segment in terms of its service to pedestrians.

Urban street segment performance from a pedestrian perspective is separately evaluated for each side of the street. *Unless otherwise stated, all variables identified in this section are specific to the subject side of the street.* If a sidewalk is not available for the subject side of the street, then it is assumed that pedestrians will walk in the street on that side (even if there is a sidewalk on the other side).

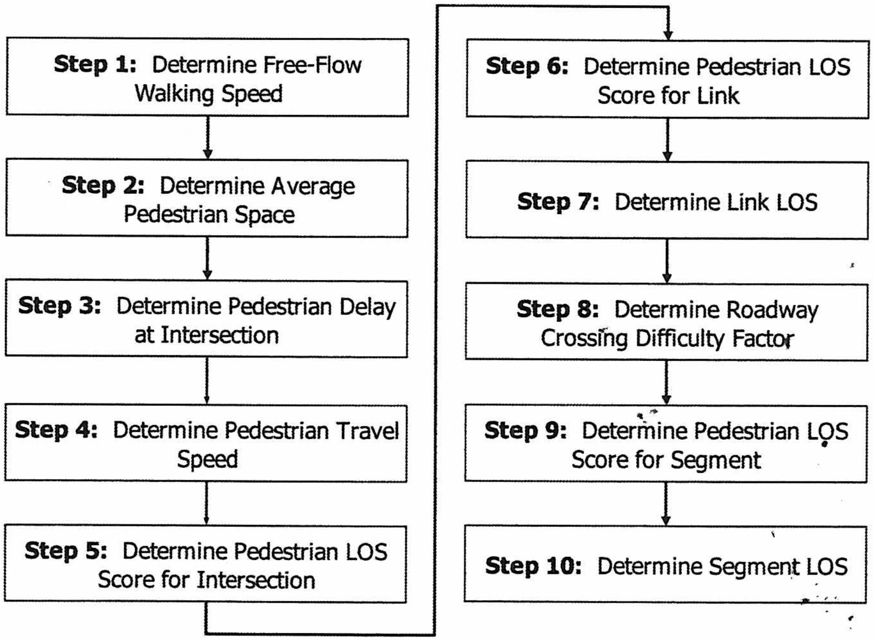
The methodology is focused on the analysis of a segment with either signal-controlled or two-way STOP-controlled boundary intersections. Chapter 18 describes a methodology for evaluating signalized intersection performance from a pedestrian perspective. No methodology exists for evaluating two-way STOP-controlled intersection performance (with the cross street STOP controlled). However, it is reasoned that this type of control has negligible influence on pedestrian service along the segment. This edition of the HCM does not include a procedure for evaluating a segment's performance when the boundary intersection is an all-way STOP-controlled intersection, a roundabout, or a signalized interchange ramp terminal.

The pedestrian methodology is applied through a series of nine steps that culminate in the determination of the segment LOS. These steps are illustrated in Exhibit 17-15. Performance measures that are estimated include

- Pedestrian travel speed,
- Average pedestrian space, and
- Pedestrian LOS scores for the link and segment.

A methodology for evaluating off-street pedestrian facilities is provided in Chapter 23, Off-Street Pedestrian and Bicycle Facilities.

Exhibit 17-15
Pedestrian Methodology for Urban Street Segments


Step 1: Determine Free-Flow Walking Speed
Step 2: Determine Average Pedestrian Space
Step 3: Determine Pedestrian Delay at Intersection
Step 4: Determine Pedestrian Travel Speed
Step 5: Determine Pedestrian LOS Score for Intersection
Step 6: Determine Pedestrian LOS Score for Link
Step 7: Determine Link LOS
Step 8: Determine Roadway Crossing Difficulty Factor
Step 9: Determine Pedestrian LOS Score for Segment
Step 10: Determine Segment LOS

Link-Based Evaluation

Steps 6 and 7 of the pedestrian methodology can be used as a stand-alone procedure for link-based evaluation of pedestrian service. This approach is regularly used by local, regional, and state transportation agencies. It offers the advantage of being less data-intensive than the full, 10-step methodology and produces results that are generally reflective of pedestrian perceptions of service along the roadway. It can be especially attractive when agencies are performing a networkwide evaluation for a large number of roadway links.

The analyst should recognize that the resulting link LOS does not consider some aspects of pedestrian travel along a segment (e.g., crossing difficulty or intersection service). For this reason, the LOS score for the link should not be aggregated for the purpose of characterizing facility performance. The analyst should also be aware that this approach precludes an integrated multimodal evaluation because it does not fully reflect segment performance.

Concepts

The methodology provides a variety of measures for evaluating segment performance in terms of its service to pedestrians. Each measure describes a different aspect of the pedestrian trip along the segment. One measure is the LOS score. This score is an indication of the typical pedestrian's perception of the overall segment travel experience. A second measure is the average speed of pedestrians traveling along the segment.

A third measure is based on the concept of "circulation area." It represents the average amount of sidewalk area available to each pedestrian walking along the segment. A larger area is more desirable from the pedestrian perspective. Exhibit 17-16 provides a qualitative description of pedestrian space that can be used to evaluate sidewalk performance from a circulation-area perspective.

Exhibit 17-16
Qualitative Description of Pedestrian Space

Pedestrian Space (ft^2/p)		
Random Flow	**Platoon Flow**	**Description**
>60	>530	Ability to move in desired path, no need to alter movements
>40–60	>90–530	Occasional need to adjust path to avoid conflicts
>24–40	>40–90	Frequent need to adjust path to avoid conflicts
>15–24	>23–40	Speed and ability to pass slower pedestrians restricted
>8–15	>11–23	Speed restricted, very limited ability to pass slower pedestrians
≤8	≤11	Speed severely restricted, frequent contact with other users

The first two columns in Exhibit 17-16 indicate a sensitivity to flow condition. Random pedestrian flow is typical of most segments. Platoon flow is appropriate for shorter segments (e.g., in downtown areas) with signalized boundary intersections.

Step 1: Determine Free-Flow Walking Speed

The *average* free-flow pedestrian walking speed S_{pf} is needed for the evaluation of urban street segment performance from a pedestrian perspective. This speed should reflect conditions in which there are negligible pedestrian-to-pedestrian conflicts and negligible adjustments in a pedestrian's desired walking path to avoid other pedestrians.

Research indicates that walking speed is influenced by pedestrian age and sidewalk grade (*6*). If 0% to 20% of pedestrians traveling along the subject segment are elderly (i.e., 65 years of age or older), an average free-flow walking speed of 4.4 ft/s is recommended for segment evaluation. If more than 20% of pedestrians are elderly, an average free-flow walking speed of 3.3 ft/s is recommended. In addition, an upgrade of 10% or greater reduces walking speed by 0.3 ft/s.

Step 2: Determine Average Pedestrian Space

Pedestrians are sensitive to the amount of space separating them from other pedestrians and obstacles as they walk along a sidewalk. Average pedestrian space is an indicator of segment performance for travel in a sidewalk. It depends on the effective sidewalk width, pedestrian flow rate, and walking speed. This step is not applicable when the sidewalk does not exist.

A. Compute Effective Sidewalk Width

The effective sidewalk width equals the total walkway width less the effective width of fixed objects located on the sidewalk and less any shy distance associated with the adjacent street or a vertical obstruction. Fixed objects can be continuous (e.g., a fence or a building face) or discontinuous (e.g., trees, poles, or benches).

The effective sidewalk width is an average value for the length of the link. It is computed by using Equation 17-22 to Equation 17-26.

Equation 17-22

$$W_E = W_T - W_{O,i} - W_{O,o} - W_{s,i} - W_{s,o} \quad \geq 0.0$$

with

Equation 17-23

$$W_{s,i} = \max(W_{buf}, 1.5)$$

Equation 17-24

$$W_{s,o} = 3.0 p_{\text{window}} + 2.0\, p_{\text{building}} + 1.5\, p_{\text{fence}}$$

Equation 17-25

$$W_{O,i} = w_{O,i} - W_{s,i} \quad \geq 0.0$$

Equation 17-26

$$W_{O,o} = w_{O,o} - W_{s,o} \quad \geq 0.0$$

where

W_E = effective sidewalk width (ft),

W_T = total walkway width (ft),

$W_{O,i}$ = adjusted fixed-object effective width on inside of sidewalk (ft),

$W_{O,o}$ = adjusted fixed-object effective width on outside of sidewalk (ft),

$W_{s,i}$ = shy distance on inside (curb side) of sidewalk (ft),

$W_{s,o}$ = shy distance on outside of sidewalk (ft),

W_{buf} = buffer width between roadway and sidewalk (ft),

p_{window} = proportion of sidewalk length adjacent to a window display (decimal),

p_{building} = proportion of sidewalk length adjacent to a building face (decimal),

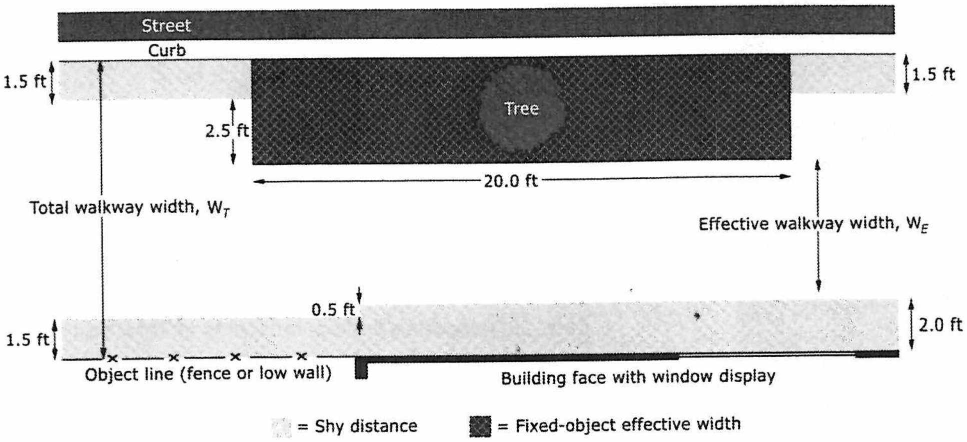
p_{fence} = proportion of sidewalk length adjacent to a fence or low wall (decimal),

$w_{O,i}$ = effective width of fixed objects on inside of sidewalk (ft), and

$w_{O,o}$ = effective width of fixed objects on outside of sidewalk (ft).

The relationship between the variables in these equations is illustrated in Exhibit 17-17.

Exhibit 17-17
Width Adjustments for Fixed Objects


Street
Curb
1.5 ft
1.5 ft
2.5 ft
Tree
20.0 ft
Total walkway width, W_T
Effective walkway width, W_E
0.5 ft
2.0 ft
1.5 ft
Object line (fence or low wall)
Building face with window display
= Shy distance
= Fixed-object effective width

The variables W_T, W_{buf}, p_{window}, p_{building}, p_{fence}, $w_{O,i}$, and $w_{O,o}$ are input variables. They represent average, or typical, values for the length of the sidewalk. Chapter 23, Off-Street Pedestrian and Bicycle Facilities, provides guidance for estimating the effective width of many common fixed objects.

Typical shy distances are shown in Exhibit 17-17. Shy distance on the inside (curb side) of the sidewalk is measured from the outside edge of the paved roadway (or face of curb, if present). It is generally considered to equal 1.5 ft. Shy distance on the outside of the sidewalk is 1.5 ft if a fence or a low wall is present, 2.0 ft if a building is present, 3.0 ft if window display is present, and 0.0 ft otherwise.

B. Compute Pedestrian Flow Rate per Unit Width

The pedestrian flow per unit width of sidewalk is computed by using Equation 17-27 for the subject sidewalk. The variable v_{ped} is an input variable.

Equation 17-27

$$v_p = \frac{v_{ped}}{60\ W_E}$$

where

v_p = pedestrian flow per unit width (p/ft/min),

v_{ped} = pedestrian flow rate in the subject sidewalk (walking in both directions) (p/h), and

W_E = effective sidewalk width (ft).

C. Compute Average Walking Speed

The average walking speed S_p is computed by using Equation 17-28. This equation is derived from the relationship between flow rate and average walking speed described in Exhibit 23-1 of Chapter 23.

Equation 17-28

$$S_p = (1 - 0.00078\ v_p^2)\ S_{pf} \quad \geq 0.5\ S_{pf}$$

where S_p = pedestrian walking speed (ft/s), S_{pf} = free-flow pedestrian walking speed (ft/s), and v_p = pedestrian flow per unit width (p/ft/min).

D. Compute Pedestrian Space

Finally, Equation 17-29 is used to compute average pedestrian space.

$$A_p = 60\,\frac{S_p}{v_p}$$

Equation 17-29

where A_p is the pedestrian space (ft²/p) and other variables are as previously defined.

The pedestrian space obtained from Equation 17-29 can be compared with the ranges provided in Exhibit 17-16 to make some judgments about the performance of the subject intersection corner.

Step 3: Determine Pedestrian Delay at Intersection

Pedestrian delay at three locations along the segment is determined in this step. Each of these delays represents an input variable for the methodology and is described in Section 1, Required Input Data.

The first delay variable represents the delay incurred by pedestrians who travel through the boundary intersection along a path that is parallel to the segment centerline d_{pp}. The second delay variable represents the delay incurred by pedestrians who cross the segment at the nearest signal-controlled crossing d_{pc}. The third delay variable represents the delay incurred by pedestrians waiting for a gap to cross the segment at an uncontrolled location d_{pw}.

Step 4: Determine Pedestrian Travel Speed

Pedestrian travel speed represents an aggregate measure of speed along the segment. It combines the delay incurred at the downstream boundary intersection plus the time required to walk the length of the segment. As such, it is typically slower than the average walking speed. The pedestrian travel speed is computed by using Equation 17-30.

$$S_{Tp,seg} = \frac{L}{\dfrac{L}{S_p} + d_{pp}}$$

Equation 17-30

where

$S_{Tp,seg}$ = travel speed of through pedestrians for the segment (ft/s),

L = segment length (ft),

S_p = pedestrian walking speed (ft/s), and

d_{pp} = pedestrian delay when walking parallel to the segment (s/p).

In general, a travel speed of 4.0 ft/s or more is considered desirable and a speed of 2.0 ft/s or less is considered undesirable.

Step 5: Determine Pedestrian LOS Score for Intersection

The pedestrian LOS score for the boundary intersection $I_{p,int}$ is determined in this step. If the boundary intersection is signalized, then the pedestrian methodology described in Chapter 18 is used for this determination. If the boundary intersection is two-way STOP controlled, then the score is equal to 0.0.

Step 6: Determine Pedestrian LOS Score for Link

The pedestrian LOS score for the link $I_{p,link}$ is calculated by using Equation 17-31.

Equation 17-31

$$I_{p,link} = 6.0468 + F_w + F_v + F_S \quad .$$

with

Equation 17-32

$$F_w = -1.2276 \ln(W_v + 0.5\, W_1 + 50\, p_{pk} + W_{buf}\, f_b + W_{aA}\, f_{sw})$$

Equation 17-33

$$F_v = 0.0091 \frac{v_m}{4\, N_{th}}$$

Equation 17-34

$$F_s = 4\left(\frac{S_R}{100}\right)^2$$

where

$I_{p,link}$ = pedestrian LOS score for link;

F_w = cross-section adjustment factor;

F_v = motorized vehicle volume adjustment factor;

F_S = motorized vehicle speed adjustment factor;

$\ln(x)$ = natural log of x;

W_v = effective total width of outside through lane, bicycle lane, and shoulder as a function of traffic volume (see Exhibit 17-18) (ft);

W_1 = effective width of combined bicycle lane and shoulder (see Exhibit 17-18) (ft);

p_{pk} = proportion of on-street parking occupied (decimal);

W_{buf} = buffer width between roadway and available sidewalk (= 0.0 if sidewalk does not exist) (ft);

f_b = buffer area coefficient = 5.37 for any continuous barrier at least 3 ft high that is located between the sidewalk and the outside edge of roadway; otherwise use 1.0;

W_A = available sidewalk width = 0.0 if sidewalk does not exist or $W_T - W_{buf}$ if sidewalk exists (ft);

W_{aA} = adjusted available sidewalk width = $\min(W_A, 10)$ (ft);

f_{sw} = sidewalk width coefficient = $6.0 - 0.3\, W_{aA}$;

v_m = midsegment demand flow rate (direction nearest to the subject sidewalk) (veh/h);

N_{th} = number of through lanes on the segment in the subject direction of travel (ln); and

S_R = motorized vehicle running speed = $(3{,}600\ L)/(5{,}280\ t_R)$ (mi/h).

The value used for several of the variables in Equation 17-32 to Equation 17-34 is dependent on various conditions. These conditions are identified in Column 1 of Exhibit 17-18. If the condition is satisfied, then the equation in Column 2 is used to compute the variable value. If it is not satisfied, then the equation in Column 3 is used. The equations in the first two rows are considered in sequence to determine the effective width of the outside lane and shoulder W_v.

Exhibit 17-18
Variables for Pedestrian LOS Score for Link

Condition	Variable When Condition Is Satisfied	Variable When Condition Is Not Satisfied
$p_{pk} = 0.0$	$W_t = W_{ol} + W_{bl} + W_{os}^*$	$W_t = W_{ol} + W_{bl}$
$v_m > 160$ veh/h or street is divided	$W_v = W_t$	$W_v = W_t(2 - 0.005\ v_m)$
$p_{pk} < 0.25$ or parking is striped	$W_1 = W_{bl} + W_{os}^*$	$W_1 = 10$

Notes: W_t = total width of the outside through lane, bicycle lane, and paved shoulder (ft);
W_{ol} = width of the outside through lane (ft);
W_{os}^* = adjusted width of paved outside shoulder; if curb is present $W_{os}^* = W_{os} - 1.5 \geq 0.0$, otherwise $W_{os}^* = W_{os}$ (ft);
W_{os} = width of paved outside shoulder (ft); and
W_{bl} = width of the bicycle lane = 0.0 if bicycle lane not provided (ft).

The buffer width coefficient determination is based on the presence of a continuous barrier in the buffer. In making this determination, repetitive vertical objects (e.g., trees or bollards) are considered to represent a continuous barrier if they are at least 3 ft high and have an average spacing of 20 ft or less. For example, the sidewalk shown in Exhibit 17-17 does not have a continuous buffer because the street trees adjacent to the curb are spaced at more than 20 ft.

The pedestrian LOS score is sensitive to the separation between pedestrians and moving vehicles; it is also sensitive to the speed and volume of these vehicles. Physical barriers and parked cars between moving vehicles and pedestrians effectively increase the separation distance and the perceived quality of service. Higher vehicle speeds or volumes lower the perceived quality of service.

If the sidewalk is not continuous for the length of the segment, then the segment should be subdivided into subsegments and each subsegment separately evaluated. For this application, a subsegment is defined to begin or end at each break in the sidewalk. Each subsegment is then separately evaluated by using Equation 17-31. Each equation variable is uniquely quantified to represent the subsegment to which it applies. The buffer width and the effective sidewalk width are each set to 0.0 ft for any subsegment without a sidewalk. The pedestrian LOS score $I_{p,link}$ is then computed as a weighted average of the subsegment scores, where the weight assigned to each score equals the portion of the segment length represented by the corresponding subsegment.

The motorized vehicle running speed is computed by using the automobile methodology, as described in a previous subsection.

Step 7: Determine Link LOS

The pedestrian LOS for the link is determined by using the pedestrian LOS score from Step 6 and the average pedestrian space from Step 2. These two performance measures are compared with their respective thresholds in Exhibit

17-3 to determine the LOS for the specified direction of travel along the subject link. If a sidewalk does not exist and pedestrians are relegated to walking in the street, then LOS is determined by using Exhibit 17-4 because the pedestrian space concept does not apply.

Step 8: Determine Roadway Crossing Difficulty Factor

The pedestrian roadway crossing difficulty factor measures the difficulty of crossing the street between boundary intersections. Segment performance from a pedestrian perspective is reduced if the crossing is perceived to be difficult.

The roadway crossing difficulty factor is based on the delay incurred by a pedestrian who crosses the subject segment. One crossing option the pedestrian may consider is to alter his or her travel path by diverting to the nearest signal-controlled crossing. This crossing location may be a midsegment signalized crosswalk or it may be a signalized intersection.

A second crossing option is to continue on the original travel path by completing a midsegment crossing at an uncontrolled location. If this type of crossing is legal along the subject segment, then the pedestrian crosses when there is an acceptable gap in the motorized vehicle stream.

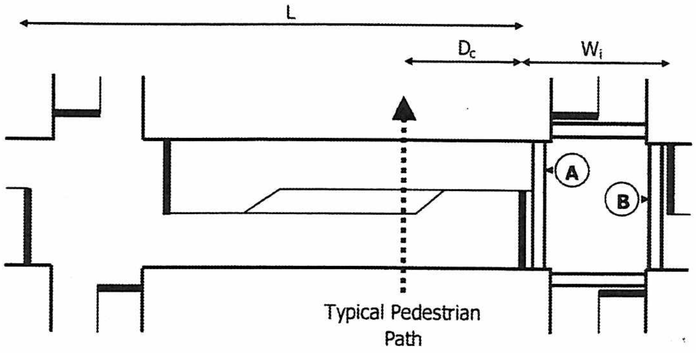
Each of these two crossing options is considered in this step, with that option requiring the least delay used as the basis for computing the pedestrian roadway crossing difficulty factor. The time to walk across the segment is common to both options and therefore is not included in the delay estimate for either option.

A. Compute Diversion Delay

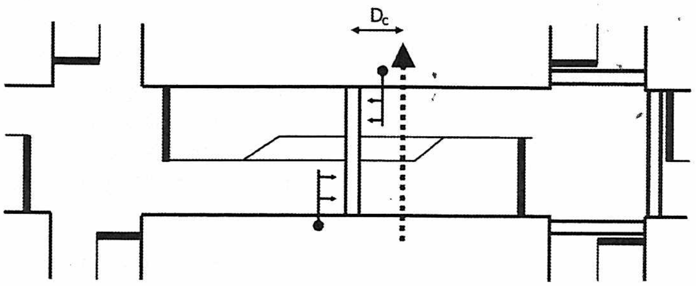
The delay incurred as a consequence of diverting to the nearest signal-controlled crossing is computed first. It includes the delay involved in walking to and from the midsegment crossing point to the nearest signal-controlled crossing and the delay waiting to cross at the signal. Hence, calculation of this delay requires knowledge of the distance to the nearest signalized crossing and its signal timing.

The distance to the nearest crossing location D_c is based on one of two approaches. The first approach is used if there is an identifiable pedestrian path (*a*) that intersects the segment and continues on beyond the segment and (*b*) on which most crossing pedestrians travel. The location of this path is shown for two cases in Exhibit 17-19. Exhibit 17-19(a) illustrates the distance D_c when the pedestrian diverts to the nearest signalized intersection. This distance is measured from the crossing location to the signalized intersection.

Exhibit 17-19
Diversion Distance Components



(a) Divert to Nearest Boundary Intersection



(b) Divert to Midsegment Signalized Crosswalk

Exhibit 17-19(b) illustrates the distance D_c when a signalized crosswalk is provided at a midsegment location. In this situation, the distance is measured from the pedestrian crossing location to the location of the signalized crosswalk. In either case, the distance D_c is an input value provided by the analyst.

The second approach is used if crossings occur somewhat uniformly along the length of the segment. In this situation the distance D_c can be assumed to equal one-third of the distance between the nearest signal-controlled crossings that bracket the subject segment.

The diversion distance to the nearest crossing is computed by using Equation 17-35.

Equation 17-35

$$D_d = 2\, D_c$$

where

D_d = diversion distance (ft), and

D_c = distance to nearest signal-controlled crossing (ft).

If the nearest crossing location is at the signalized intersection and the crossing is at Location A in Exhibit 17-19(a), then Equation 17-35 applies directly. If the nearest crossing location is at the signalized intersection but the crossing is at Location B, then the distance obtained from Equation 17-35 should be increased by adding two increments of the intersection width W_i.

The delay incurred due to diversion is calculated by using Equation 17-36.

Equation 17-36

$$d_{pd} = \frac{D_d}{S_p} + d_{pc}$$

where

d_{pd} = pedestrian diversion delay (s/p),

D_d = diversion distance (ft),

S_p = pedestrian walking speed (ft/s), and

d_{pc} = pedestrian delay when crossing the segment at the nearest signal-controlled crossing (s/p).

The pedestrian delay incurred when crossing at the nearest signal-controlled crossing was determined in Step 3.

B. Compute Roadway Crossing Difficulty Factor

The roadway crossing difficulty factor is computed by using Equation 17-37.

Equation 17-37

$$F_{cd} = 1.0 + \frac{0.10\, d_{px} - (0.318\, I_{p,link} + 0.220\, I_{p,int} + 1.606)}{7.5}$$

where

F_{cd} = roadway crossing difficulty factor,

d_{px} = crossing delay = $\min(d_{pd}, d_{pw}, 60)$ (s/p),

d_{pd} = pedestrian diversion delay (s/p),

d_{pw} = pedestrian waiting delay (s/p),

$I_{p,link}$ = pedestrian LOS score for link, and

$I_{p,int}$ = pedestrian LOS score for intersection.

If the factor obtained from Equation 17-37 is less than 0.80, then it is set equal to 0.80. If the factor is greater than 1.20, then it is set equal to 1.20.

The pedestrian waiting delay was determined in Step 3. If a midsegment crossing is illegal, then the crossing delay determination does not include consideration of the pedestrian waiting delay d_{pw} [i.e., $d_{px} = \min(d_{pd}, 60)$].

Step 9: Determine Pedestrian LOS Score for Segment

The pedestrian LOS score for the segment is computed by using Equation 17-38.

Equation 17-38

$$I_{p,seg} = F_{cd}\left(0.318\, I_{p,link} + 0.220\, I_{p,int} + 1.606\right)$$

where $I_{p,seg}$ is the pedestrian LOS score for the segment and other variables are as previously defined.

Step 10: Determine Segment LOS

The pedestrian LOS for the segment is determined by using the pedestrian LOS score from Step 9 and the average pedestrian space from Step 2. These two performance measures are compared with their respective thresholds in Exhibit

17-3 to determine the LOS for the specified direction of travel along the subject segment. If a sidewalk does not exist and pedestrians are relegated to walking in the street, then LOS is determined by using Exhibit 17-4 because the pedestrian space concept does not apply.

BICYCLE MODE

This subsection describes the methodology for evaluating the performance of an urban street segment in terms of its service to bicyclists.

Urban street segment performance from a bicyclist perspective is separately evaluated for each travel direction along the street. *Unless otherwise stated, all variables identified in this section are specific to the subject direction of travel.* The bicycle is assumed to travel in the street (possibly in a bicycle lane) and in the same direction as adjacent motorized vehicles.

The methodology is focused on the analysis of a segment with either signal-controlled or two-way STOP-controlled boundary intersections. Chapter 18 describes a methodology for evaluating signalized intersection performance from a bicyclist perspective. No methodology exists for evaluating two-way STOP-controlled intersection performance (with the cross street STOP controlled). However, the influence of this type of control is incorporated in the methodology for evaluating segment performance. This edition of the HCM does not include a procedure for evaluating a segment's performance when the boundary intersection is an all-way STOP-controlled intersection, a roundabout, or a signalized interchange ramp terminal.

The bicycle methodology is applied through a series of seven steps that culminate in the determination of the segment LOS. These steps are illustrated in Exhibit 17-20. Performance measures that are estimated include bicycle travel speed and LOS scores for the link and segment.

A methodology for evaluating off-street bicycle facilities is provided in Chapter 23, Off-Street Pedestrian and Bicycle Facilities.

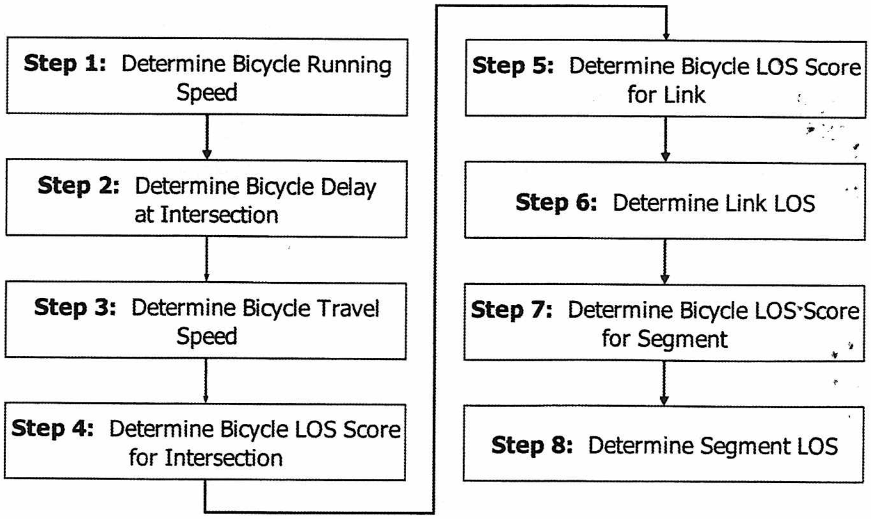

Step 1: Determine Bicycle Running Speed
Step 2: Determine Bicycle Delay at Intersection
Step 3: Determine Bicycle Travel Speed
Step 4: Determine Bicycle LOS Score for Intersection
Step 5: Determine Bicycle LOS Score for Link
Step 6: Determine Link LOS
Step 7: Determine Bicycle LOS Score for Segment
Step 8: Determine Segment LOS

Exhibit 17-20
Bicycle Methodology for Urban Street Segments

Link-Based Evaluation

Steps 5 and 6 of the bicycle methodology can be used as a stand-alone procedure for link-based evaluation of bicycle service. This approach is regularly used by local, regional, and state transportation agencies. It offers the advantage of being less data-intensive than the full, eight-step methodology and produces results that are generally reflective of bicyclist perceptions of service along the roadway. It can be especially attractive when agencies are performing a networkwide evaluation for a large number of roadway links.

The analyst should recognize that the resulting link LOS does not consider some aspects of bicycle travel along a segment (e.g., intersection service). For this reason, the LOS score for the link should not be aggregated for the purpose of characterizing facility performance. The analyst should also be aware that this approach precludes an integrated multimodal evaluation because it does not fully reflect segment performance.

Step 1: Determine Bicycle Running Speed

An estimate of the *average* bicycle running speed S_b is determined in this step. The best basis for this estimate is a field measurement of midsegment bicycle speed on representative streets in the vicinity of the subject street. In the absence of this information, it is recommended that the average running speed of bicycles be taken as 15 mi/h between signalized intersections (7). It is recognized that many factors might affect bicycle speed, including adjacent motor vehicle traffic, adjacent on-street parking activity, commercial and residential driveways, lateral obstructions, and significant grades. To date, research is not available to make any specific recommendations as to the effect of these factors on speed.

Step 2: Determine Bicycle Delay at Intersection

Bicycle delay at the boundary intersection d_b is computed in this step. This delay is incurred by bicyclists who travel through the intersection in the same lane as (or in a bicycle lane that is parallel to the lanes used by) segment through vehicles.

If the boundary intersection is two-way STOP controlled (where the subject approach is uncontrolled), then the delay is equal to 0.0 s/bicycle. If the boundary intersection is signalized, then the delay is computed by using the methodology described in Chapter 18, Signalized Intersections.

Step 3: Determine Bicycle Travel Speed

Bicycle travel speed represents an aggregate measure of speed along the segment. It combines the delay incurred at the downstream boundary intersection and the time required to ride the length of the segment. As such, it is typically slower than the average bicycle running speed. The average bicycle travel speed is computed by using Equation 17-39.

Equation 17-39

$$S_{Tb,seg} = \frac{3{,}600\ L}{5{,}280\ (t_{Rb} + d_b)}$$

where

$S_{Tb,seg}$ = travel speed of through bicycles along the segment (mi/h),

L = segment length (ft),

t_{Rb} = segment running time of through bicycles = (3,600 L)/(5,280 S_b) (s),

S_b = bicycle running speed (mi/h), and

d_b = bicycle control delay (s/bicycle).

In general, a travel speed of 10.0 mi/h or more is considered desirable and a speed of 5.0 mi/h or less is considered undesirable.

Step 4: Determine Bicycle LOS Score for Intersection

The bicycle LOS score for the boundary intersection $I_{b,int}$ is determined in this step. If the boundary intersection is signalized, then the bicycle methodology described in Chapter 18 is used for this determination. If the boundary intersection is two-way STOP controlled, then the score is equal to 0.0.

Step 5: Determine Bicycle LOS Score for Link

The bicycle LOS score for the segment $I_{b,link}$ is calculated by using Equation 17-40.

$$I_{b,link} = 0.760 + F_w + F_v + F_S + F_p$$

Equation 17-40

with

$$F_w = -0.005\, W_e^2$$

Equation 17-41

$$F_v = 0.507 \ln\left(\frac{v_{ma}}{4\, N_{th}}\right)$$

Equation 17-42

$$F_S = 0.199\,[1.1199 \ln(S_{Ra} - 20) + 0.8103](1 + 0.1038\; P_{HVa})^2$$

Equation 17-43

$$F_p = \frac{7.066}{P_c^2}$$

Equation 17-44

where

$I_{b,link}$ = bicycle LOS score for link,

F_w = cross-section adjustment factor,

F_v = motorized vehicle volume adjustment factor,

F_S = motorized vehicle speed adjustment factor,

F_p = pavement condition adjustment factor,

$\ln(x)$ = natural log of x,

W_e = effective width of outside through lane (see Exhibit 17-21) (ft),

v_{ma} = adjusted midsegment demand flow rate (see Exhibit 17-21) (veh/h),

N_{th} = number of through lanes on the segment in the subject direction of travel (ln),

S_{Ra} = adjusted motorized vehicle running speed (see Exhibit 17-21) (mi/h),

P_{HVa} = adjusted percent heavy vehicles in midsegment demand flow rate (see Exhibit 17-21) (%), and

P_c = pavement condition rating (see Exhibit 17-7).

The value used for several of the variables in Equation 17-41 to Equation 17-44 is dependent on various conditions. These conditions are identified in Column 1 of Exhibit 17-21. If the condition is satisfied, then the equation in Column 2 is used to compute the variable value. If it is not satisfied, then the equation in Column 3 is used. The equations in the first three rows are considered in sequence to determine the effective width of the outside through lane W_e.

The motorized vehicle running speed is computed by using the automobile methodology described in a previous subsection.

Step 6: Determine Link LOS

The bicycle LOS for the link is determined by using the bicycle LOS score from Step 5. This performance measure is compared with the thresholds in Exhibit 17-4 to determine the LOS for the specified direction of travel along the subject link.

Exhibit 17-21
Variables for Bicycle LOS Score for Link

Condition	Variable When Condition Is Satisfied	Variable When Condition Is Not Satisfied
$p_{pk} = 0.0$	$W_t = W_{ol} + W_{bl} + W_{os}^*$	$W_t = W_{ol} + W_{bl}$
$v_m > 160$ veh/h or street is divided	$W_v = W_t$	$W_v = W_t (2 - 0.005\ v_m)$
$W_{bl} + W_{os}^* < 4.0$ ft	$W_e = W_v - 10\ p_{pk} \geq 0.0$	$W_e = W_v + W_{bl} + W_{os}^* - 20\ p_{pk} \geq 0.0$
$v_m (1 - 0.01\ P_{HV}) < 200$ veh/h and $P_{HV} > 50\%$	$P_{HVa} = 50\%$	$P_{HVa} = P_{HV}$
$S_R < 21$ mi/h	$S_{Ra} = 21$ mi/h	$S_{Ra} = S_R$
$v_m > 4\ N_{th}$	$v_{ma} = v_m$	$v_{ma} = 4\ N_{th}$

Notes:
W_t = total width of the outside through lane, bicycle lane, and paved shoulder (ft);
W_{ol} = width of outside through lane (ft);
W_{os}^* = adjusted width of paved outside shoulder; if curb is present $W_{os}^* = W_{os} - 1.5 \geq 0.0$, otherwise $W_{os}^* = W_{os}$ (ft);
W_{os} = width of paved outside shoulder (ft);
W_{bl} = width of bicycle lane = 0.0 if bicycle lane not provided (ft);
W_v = effective total width of outside through lane, bicycle lane, and shoulder as a function of traffic volume (ft);
p_{pk} = proportion of on-street parking occupied (decimal);
v_m = midsegment demand flow rate (veh/h);
P_{HV} = percent heavy vehicles in the midsegment demand flow rate (%), and
S_R = motorized vehicle running speed (mi/h).

Step 7: Determine Bicycle LOS Score for Segment

The bicycle LOS score for the segment is computed by using Equation 17-45.

Equation 17-45

$$I_{b,seg} = 0.160\ I_{b,link} + 0.011\ F_{bi}\ e^{I_{b,int}} + 0.035 \frac{N_{ap,s}}{(L/5280)} + 2.85$$

where

$I_{b,seg}$ = bicycle LOS score for segment;

$I_{b,link}$ = bicycle LOS score for link;

F_{bi} = indicator variable for boundary intersection control type = 1.0 if signalized, 0.0 if two-way STOP controlled;

$I_{b,int}$ = bicycle LOS score for intersection; and

$N_{ap,s}$ = number of access point approaches on the right side in the subject direction of travel (points).

The count of access point approaches used in Equation 17-45 includes both public street approaches and driveways on the right side of the segment in the subject direction of travel.

Step 8: Determine Segment LOS

The bicycle LOS for the segment is determined by using the segment bicycle LOS score from Step 7. This performance measure is compared with the thresholds in Exhibit 17-4 to determine the LOS for the specified direction of travel along the subject segment.

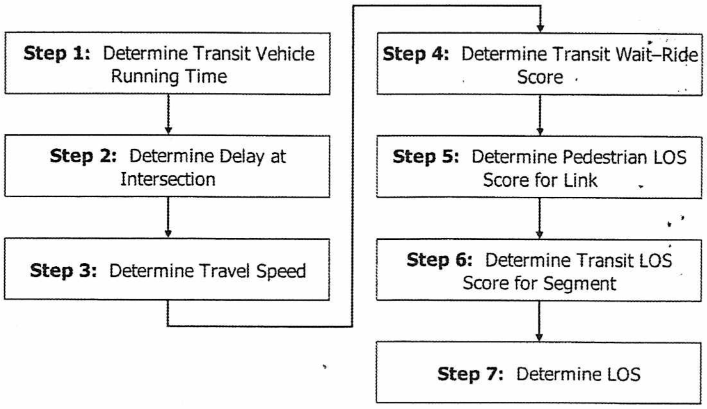
TRANSIT MODE

This subsection describes the methodology for evaluating the performance of an urban street segment in terms of its service to transit passengers.

Urban street segment performance from a transit-passenger perspective is separately evaluated for each travel direction along the street. *Unless otherwise stated, all variables identified in this section are specific to the subject direction of travel.*

The methodology is applicable to public transit vehicles operating in mixed traffic or exclusive lanes and stopping along the street. Procedures for estimating transit vehicle performance on grade-separated or non-public-street rights-of-way, along with procedures for estimating origin–destination service quality, are provided in the *Transit Capacity and Quality of Service Manual* (3).

The transit methodology is applied through a series of six steps that culminate in the determination of segment LOS. These steps are illustrated in Exhibit 17-22. Performance measures that are estimated include transit travel speed along the street, transit wait–ride score, and a LOS score reflective of all transit service stopping within or near the segment.



Step 1: Determine Transit Vehicle Running Time
Step 2: Determine Delay at Intersection
Step 3: Determine Travel Speed
Step 4: Determine Transit Wait–Ride Score
Step 5: Determine Pedestrian LOS Score for Link
Step 6: Determine Transit LOS Score for Segment
Step 7: Determine LOS

Exhibit 17-22
Transit Methodology for Urban Street Segments

In applying Equation 19-66 and Equation 19-67, the delay for all Rank 1 major-street movements is assumed to be 0 s/veh. LOS is not defined for an overall intersection because major-street movements with 0 s of delay typically result in a weighted average delay that is extremely low. As such, total intersection control delay calculations are typically used only when comparing control delay among different types of traffic control, such as two-way STOP control versus all-way STOP control.

Step 13: Compute 95th Percentile Queue Lengths

Queue length is an important consideration at unsignalized intersections. Theoretical studies and empirical observations have demonstrated that the probability distribution of queue lengths for any minor movement at an unsignalized intersection is a function of the capacity of the movement and the volume of traffic being served during the analysis period. Equation 19-68 can be used to estimate the 95th percentile queue length for any minor movement at an unsignalized intersection during the peak 15-min period on the basis of these two parameters as follows (*9*):

Equation 19-68

$$Q_{95} \approx 900T\left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{c_{m,x}} - 1\right)^2 + \frac{\left(\frac{3{,}600}{c_{m,x}}\right)\left(\frac{v_x}{c_{m,x}}\right)}{150T}}\right]\left(\frac{c_{m,x}}{3{,}600}\right)$$

where

Q_{95} = 95th percentile queue (veh),
v_x = flow rate for movement x (veh/h),
$c_{m,x}$ = capacity of movement x (veh/h), and
T = analysis time period (0.25 h for a 15-min period) (h).

The mean queue length is computed as the product of the average delay per vehicle and the flow rate for the movement of interest. The expected total delay (vehicle hours per hour) equals the expected number of vehicles in the average queue; that is, the total hourly delay and the average queue are numerically identical. For example, four vehicle hours per hour of delay can be used interchangeably with an average queue length of four vehicles during the hour.

PEDESTRIAN MODE

The TWSC intersection methodology for the pedestrian mode is applied through a series of steps requiring input data related to vehicle and pedestrian volumes, geometric conditions, and motorist yield rates to pedestrians. These data are used to calculate the average pedestrian delay associated with pedestrian crossings of unsignalized and non-STOP-controlled roadways. The required steps are illustrated in Exhibit 19-16.

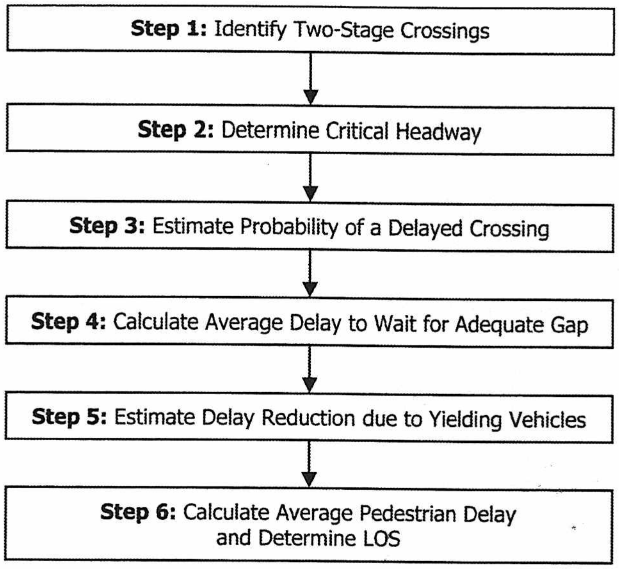

Step 1: Identify Two-Stage Crossings
Step 2: Determine Critical Headway
Step 3: Estimate Probability of a Delayed Crossing
Step 4: Calculate Average Delay to Wait for Adequate Gap
Step 5: Estimate Delay Reduction due to Yielding Vehicles
Step 6: Calculate Average Pedestrian Delay and Determine LOS

Exhibit 19-16
TWSC Pedestrian Methodology

Step 1: Identify Two-Stage Crossings

When a raised pedestrian-median refuge island is available, pedestrians typically cross in two stages, similar to the two-stage gap-acceptance described for automobiles earlier in this chapter. Determination of whether a pedestrian-median refuge exists may require engineering judgment. The main issue to determine is whether pedestrians cross the traffic streams in one or two stages. When pedestrians cross in two stages, pedestrian delay should be estimated separately for each stage of the crossing by using the procedures described in Steps 2 to 6. To determine pedestrian LOS, the pedestrian delay for each stage should be summed to establish the average pedestrian delay associated with the entire crossing. This service measure is used to determine pedestrian LOS for a TWSC intersection with two-stage crossings.

Step 2: Determine Critical Headway

Critical headway for pedestrians.

The procedure for estimating the critical headway is similar to that described for automobiles. The critical headway is the time in seconds below which a pedestrian will not attempt to begin crossing the street. Pedestrians use their judgment to determine whether the available headway between conflicting vehicles is long enough for a safe crossing. If the available headway is greater than the critical headway, it is assumed that the pedestrian will cross, but if the available headway is less than the critical headway, it is assumed that the pedestrian will not cross.

For a single pedestrian, critical headway is computed with Equation 19-69:

$$t_c = \frac{L}{S_p} + t_s$$

Equation 19-69

where

t_c = critical headway for a single pedestrian (s),

S_p = average pedestrian walking speed (ft/s),

L = crosswalk length (ft), and

t_s = pedestrian start-up time and end clearance time (s).

Pedestrian platooning.

If pedestrian platooning is observed in the field, then the spatial distribution of pedestrians should be computed with Equation 19-70. If no platooning is observed, the spatial distribution of pedestrians is assumed to be 1.

Equation 19-70

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where

N_p = spatial distribution of pedestrians (ped);

N_c = total number of pedestrians in the crossing platoon, from Equation 19-71 (ped);

W_c = crosswalk width (ft); and

8.0 = default clear effective width used by a single pedestrian to avoid interference when passing other pedestrians (ft).

To compute spatial distribution, the analyst must make field observations or estimate the platoon size by using Equation 19-71:

Equation 19-71

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where

N_c = total number of pedestrians in the crossing platoon (ped),

v_p = pedestrian flow rate (ped/s),

v = vehicular flow rate (veh/s), and

t_c = single pedestrian critical headway (s).

Group critical headway is determined with Equation 19-72:

Equation 19-72

$$t_{c,G} = t_c + 2(N_p - 1)$$

where

$t_{c,G}$ = group critical headway (s),

t_c = critical headway for a single pedestrian (s), and

N_p = spatial distribution of pedestrians (ped).

Step 3: Estimate Probability of a Delayed Crossing

On the basis of calculation of the critical headway t_G, the probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

Assuming random arrivals of vehicles on the major street, and equal distribution of vehicles among all through lanes on the major street, the probability of encountering a headway exceeding the critical headway in any given lane can be estimated by using a Poisson distribution. The likelihood that a gap in a given lane does not exceed the critical headway is thus the complement as shown in Equation 19-73. Because traffic is assumed to be distributed independently in each through lane, Equation 19-74 shows the probability that a pedestrian incurs nonzero delay at a TWSC crossing.

Equation 19-73

$$P_b = 1 - e^{\frac{-t_{c,G}v}{L}}$$

Equation 19-74

$$P_d = 1 - (1 - P_b)^L$$

where

P_b = probability of a blocked lane,

P_d = probability of a delayed crossing,

L = number of through lanes crossed,

$t_{c,G}$ = group critical headway (s), and

v = vehicular flow rate (veh/s).

Step 4: Calculate Average Delay to Wait for Adequate Gap

Research indicates that average delay to pedestrians at unsignalized crossings, assuming that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap, depends on the critical headway, the vehicular flow rate of the subject crossing, and the mean vehicle headway (*10*). The average delay per pedestrian to wait for an adequate gap is given by Equation 19-75.

Equation 19-75

$$d_g = \frac{1}{v}\left(e^{vt_{c,G}} - vt_{c,G} - 1\right)$$

where

d_g = average pedestrian gap delay (s),

$t_{c,G}$ = group critical headway (s), and

v = vehicular flow rate (veh/s).

The average delay for any pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay) is thus a function of P_d and d_g, as shown in Equation 19-76:

Equation 19-76

$$d_{gd} = \frac{d_g}{P_d}$$

where

d_{gd} = average gap delay for pedestrians who incur nonzero delay,

d_g = average pedestrian gap delay (s), and

P_d = probability of a delayed crossing.

Step 5: Estimate Delay Reduction due to Yielding Vehicles

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (*a*) a gap greater than the critical headway is available, or (*b*) motor vehicles yield and allow the pedestrian to cross. Equation 19-75 estimates pedestrian delay when motorists on the major approaches do not yield to pedestrians. Where motorist yield rates are significantly higher than zero, pedestrians will experience considerably less delay than that estimated by Equation 19-75.

In the United States, motorists are legally required to yield to pedestrians, under most circumstances, in both marked and unmarked crosswalks. However, actual motorist yielding behavior varies considerably. Motorist yield rates are influenced by a range of factors, including roadway geometry, travel speeds, pedestrian crossing treatments, local culture, and law enforcement practices.

Research (*11*, *12*) provides information on motorist responses to typical pedestrian crossing treatments, as shown in Exhibit 19-17. The exhibit shows results from two separate data collection methods. Staged data were collected with pedestrians trained by the research team to maintain consistent positioning, stance, and aggressiveness in crossing attempts. Unstaged data were collected through video recordings of the general population. The values shown in Exhibit 19-17 are based on a limited number of sites and do not encompass the full range of available crossing treatments. As always, practitioners should supplement these values with local knowledge and engineering judgment.

Exhibit 19-17
Effect of Pedestrian Crossing Treatments on Motorist Yield Rates

Crossing Treatment	Staged Pedestrians Number of Sites	Staged Pedestrians Mean Yield Rate, %	Unstaged Pedestrians Number of Sites	Unstaged Pedestrians Mean Yield Rate, %
Overhead flashing beacon (push button activation)	3	47	4	49
Overhead flashing beacon (passive activation)	3	31	3	67
Pedestrian crossing flags	6	65	4	74
In-street crossing signs (25–30 mi/h)	3	87	3	90
High-visibility signs and markings (35 mi/h)	2	17	2	20
High-visibility signs and markings (25 mi/h)	1	61	1	91
Rectangular rapid-flash beacon	N/A	N/A	17	81

Source: Fitzpatrick et al. (*11*) and Shurbutt et al. (*12*).

Depending on the crossing treatment and other factors, motorist behavior varies significantly.

It is possible for pedestrians to incur less actual delay than d_g because of yielding vehicles. The likelihood of this situation occurring is a function of vehicle volumes, motorist yield rates, and number of through lanes on the major street. Consider a pedestrian waiting for a crossing opportunity at a TWSC intersection, with vehicles in each conflicting through lane arriving every h seconds. On average, a potential yielding event will occur every h seconds, where $P(Y)$ represents the probability of motorists yielding for a given event. As vehicles are assumed to arrive randomly, each potential yielding event is considered to be independent.

For any given yielding event, each through lane is in one of two states:

1. Clear—no vehicles are arriving within the critical headway window, or
2. Blocked—a vehicle is arriving within the critical headway window. The pedestrian may cross only if vehicles in each blocked lane choose to yield.

If not, the pedestrian must wait an additional h seconds for the next yielding event. On average, this process will be repeated until the wait exceeds the expected delay required for an adequate gap in traffic (d_{gd}), at which point the average pedestrian will receive an adequate gap in traffic and will be able to cross the street without having to depend on yielding motorists.

Thus, average pedestrian delay can be calculated with Equation 19-77, where the first term in the equation represents expected delay from crossings occurring when motorists yield, and the second term represents expected delay from crossings where pedestrians wait for an adequate gap.

Equation 19-77

$$d_p = \sum_{i=1}^{n} h(i-0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i) \right) d_{gd}$$

where

d_p = average pedestrian delay (s),

i = crossing event ($i = 1$ to n),

h = average headway for each through lane,

$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i, and

n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available.

Equation 19-77 requires the calculation of $P(Y_i)$. The probabilities $P(Y_i)$ that motorists will yield for a given crossing event are considered below for pedestrian crossings of one, two, three, and four through lanes.

One-Lane Crossing

Under the scenario in which a pedestrian crosses one through lane, $P(Y_i)$ is found simply. When $i = 1$, $P(Y_i)$ is equal to the probability of a delayed crossing P_d multiplied by the motorist yield rate, M_y. For $i = 2$, $P(Y_i)$ is equal to M_y multiplied by the probability that the second yielding event occurs (i.e., that the pedestrian did not cross on the first yielding event), $P_d^*(1 - M_y)$. Equation 19-78 gives $P(Y_i)$ for any i.

Equation 19-78

$$P(Y_i) = P_d M_y (1 - M_y)^{i-1}$$

where

M_y = motorist yield rate (decimal), and

i = crossing event ($i = 1$ to n).

Two-Lane Crossing

For a two-lane pedestrian crossing at a TWSC intersection, $P(Y_i)$ requires either (*a*) motorists in both lanes to yield simultaneously if both lanes are blocked, or (*b*) a single motorist to yield if only one lane is blocked. Because these cases are mutually exclusive, where $i = 1$, $P(Y_i)$ is equal to Equation 19-79:

Equation 19-79

$$P(Y_1) = 2P_b(1-P_b)M_y + P_b{}^2M_y{}^2$$

Equation 19-80 shows $P(Y_i)$ where i is greater than 1. Equation 19-80 is equivalent to Equation 19-79 if $P(Y_0)$ is set to equal 0.

Equation 19-80

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2M_y^2)}{P_d}\right]$$

Three-Lane Crossing

A three-lane crossing follows the same principles as a two-lane crossing. Equation 19-81 shows the calculation for $P(Y_i)$:

Equation 19-81

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] \times \left[\frac{P_b^3M_y^3 + 3P_b^2(1-P_b)M_y^2 + 3P_b(1-P_b)^2M_y}{P_d}\right]$$

where $P(Y_0) = 0$.

Four-Lane Crossing

A four-lane crossing follows the same principles as above. Equation 19-82 shows the calculation for $P(Y_i)$:

Equation 19-82

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] \times$$

$$\left[\frac{P_b^4M_y^4 + 4P_b^3(1-P_b)M_y^3 + 6P_b^2(1-P_b)^2M_y^2 + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

where $P(Y_0) = 0$.

Step 6: Calculate Average Pedestrian Delay and Determine LOS

The delay experienced by a pedestrian is the service measure. Exhibit 19-2 lists LOS criteria for pedestrians at TWSC intersections based on pedestrian delay. Pedestrian delay at TWSC intersections with two-stage crossings is equal to the sum of the delay for each stage of the crossing.

BICYCLE MODE

As of the publication date of this edition of the HCM, no methodology specific to bicyclists has been developed to assess the performance of bicyclists at TWSC intersections, as few data are available in the United States to support model calibration or LOS definitions. Depending on individual comfort level, ability, geometric conditions, and traffic conditions, bicyclists may travel through the intersection either as a motor vehicle or as a pedestrian. Critical headway distributions have been identified in the research (*13*, *14*) for bicycles crossing two-lane major streets. Data on critical headways for bicycles under many circumstances are not readily available, however. Bicycles also differ from motor vehicles in that they normally do not queue linearly at a STOP sign. Instead, multiple bicycles often use the same gap in the vehicular traffic stream. This fact probably affects the determination of bicycle follow-up time. This phenomenon and others described in this section have not been adequately researched and are not explicitly included in the methodology.

Step 16: Compute Queue Lengths

Research (3) has determined that the methodology for predicting queues at TWSC intersections can be applied to AWSC intersections. As such, the mean queue length is computed as the product of the average delay per vehicle and the flow rate for the movement of interest.

Equation 20-33 can be used to calculate the 95th percentile queue for each approach lane.

$$Q_{95} \approx \frac{900T}{h_d}\left[(x-1)+\sqrt{(x-1)^2+\frac{h_d x}{150T}}\right]$$

Equation 20-33

where

Q_{95} = 95th percentile queue (veh),

x = $vh_d/3{,}600$ = degree of utilization,

h_d = departure headway (s), and

T = length of analysis period (h).

PEDESTRIAN MODE

Data collection and research are needed to determine an appropriate LOS methodology for pedestrians at AWSC intersections.

Applying the LOS procedures used to determine pedestrian delay at TWSC intersections to AWSC intersections does not produce intuitive or usable results. The TWSC delay calculations apply only for crossings where conflicting traffic is not STOP-controlled (i.e., pedestrians crossing the major street at a TWSC intersection). Approaches where conflicting traffic is STOP-controlled (i.e., pedestrians crossing the minor street at a TWSC intersection) are assumed to result in negligible delay for pedestrians, as vehicles are required to stop and wait for conflicting vehicle and pedestrian traffic before proceeding.

As such, applying the TWSC methodology to pedestrians at AWSC intersections results in negligible delay for all pedestrians at all approaches. The reality of AWSC intersection operations for pedestrians is much different; however, and generally results in at least some delay for pedestrians. The amount of delay incurred will depend on a number of operating and geometric characteristics of the intersection in question. While no quantitative methodology accounting for these factors is available, several of the most important factors are discussed qualitatively below.

The operational characteristics of AWSC intersections for pedestrians largely depend on driver behavior. In most cases, drivers are legally required to yield to pedestrians crossing or preparing to cross AWSC intersections. However, it should be expected that operations differ significantly depending on enforcement levels, region of the country, and location (e.g., urban, suburban, or rural).

Traffic Volumes

At intersections with relatively low traffic volumes, there are generally no standing queues of vehicles at AWSC approaches. In these cases, pedestrians attempting to cross an approach of the intersection will typically experience little or no delay, as they will be able to proceed almost immediately after reaching the intersection.

At AWSC intersections with higher volumes, there are typically standing queues of motor vehicles on each approach. These intersections operate in a two-phase or four-phase sequence, as described earlier and depicted in Exhibit 20-3. In these situations, the arrival of a pedestrian does not typically disrupt the normal phase operations of the intersection. Rather, the pedestrian is often forced to wait until the phase arrives for vehicles in the approach moving adjacent to the pedestrian.

Under a scenario in which the intersection functions under the operations described above for pedestrians, average pedestrian delay might be expected to be half of the time needed to cycle through all phases for the particular intersection, assuming random arrival of pedestrians. However, several other factors may also affect pedestrian delay and operations at AWSC intersections, as described below.

Number of Approach Lanes

As the number of approach lanes at AWSC intersections increases, pedestrian crossing distance increases proportionally, resulting in significantly longer pedestrian crossing times compared with single-lane intersections. In addition, vehicles already in the intersection or about to enter the intersection take longer to complete their movement. As a result, pedestrians at multilane AWSC intersections may wait longer before taking their turn to cross.

Proportion of Turning Traffic

The ability of a pedestrian to cross at an AWSC intersection may also depend on the proportion of through motor vehicle traffic to turning motor vehicle traffic. As described above, pedestrians may often cross during the phase in which adjacent motor vehicle traffic traverses the intersection. However, when an adjacent motor vehicle is turning, that vehicle will conflict with pedestrians attempting to cross. Because of the additional conflicts with pedestrians created by turning vehicles at AWSC intersections, pedestrian delay may be expected to rise as the proportion of turning vehicles increases, similar to the effect that turning proportion has on vehicular delay.

Pedestrian Volumes

Under most circumstances, there is adequate capacity for all pedestrians queued for a given movement at an AWSC intersection to cross simultaneously with adjacent motor vehicle traffic. However, in locations with very high pedestrian volumes, this may not be the case. The total pedestrian capacity of a particular AWSC intersection phase is limited by both the width of the crosswalk (how many pedestrians can cross simultaneously) and driver behavior.

In situations in which not all queued pedestrians may cross during a particular phase, pedestrian delay will increase, as some pedestrians will be forced to wait through an additional cycle of intersection phases before crossing. However, pedestrian volumes in this range are unlikely to occur often; rather, intersections with pedestrian volumes high enough to cause significant delay are typically signalized.

BICYCLE MODE

Where bicycles queue with motor vehicles on AWSC approaches, the procedures described to estimate motor vehicle delay can be applied to bicycles. However, bicycles differ from motor vehicles in that they do not queue linearly at STOP signs. Instead, multiple bicycles often cross at the same time as the adjacent vehicular traffic stream. This phenomenon has not been researched as of the time of publication of this edition of the HCM and is not explicitly included in the methodology.

Where an AWSC approach provides a bicycle lane, bicycle delay will be significantly different and, in general, lower than motor vehicle delay. The exception is bicycles intending to turn left; those cyclists will typically queue with motor vehicles. Where bicycle lanes are available, bicycles are able to move unimpeded until reaching the stop line, as the bike lane allows the cyclist to pass any queued motor vehicles on the right. In this situation, bicycles will still incur delay upon reaching the intersection.

In most cases, bicycles will be able to travel through the intersection concurrently with adjacent motor vehicle traffic. This, in effect, results in multilane operations, with the bike lane serving as the curb lane, meaning that bicycles will be delayed from the time of arrival at the intersection until the adjacent motor vehicle phase occurs. As noted above, multiple bicycles will likely be able to cross simultaneously through the intersection. Finally, even where bicycle lanes are not available, many cyclists still pass queued motor vehicles on the right, resulting in lower effective bicycle delay compared with motor vehicle delay.

The critical intersection volume-to-capacity ratio can be misleading when it is used to evaluate the overall sufficiency of the intersection geometry, as is often required in planning applications. The problem is that low flow rates dictate the need for short cycle lengths to minimize delay. Yet, Equation 18-17 indicates that the desired shorter cycle length produces a higher volume-to-capacity ratio. Therefore, a relatively large value of X_c (provided that it is less than 1.0) is not a certain indication of poor operation. Rather, it means that closer attention must be paid to the adequacy of phase duration and queue size, especially for the critical phases.

Volume-to-Capacity Ratio and Delay Combinations

In some cases, delay is high even when the volume-to-capacity ratio is low. In these situations, poor progression, a notably long cycle length, or an inefficient phase plan is generally the cause. When the intersection is part of a coordinated system, the cycle length is determined by system considerations, and alterations at individual intersections may not be practical.

It is possible that delay is at acceptable levels even when the volume-to-capacity ratio is high. This situation can occur when some combination of the following conditions exists: the cycle length is relatively short, the analysis period is short, the lane group capacity is high, and there is no initial queue. If a residual queue is created in this scenario, then the conduct of a multiple-period analysis is necessary to gain a true picture of the delay.

When both delay levels and volume-to-capacity ratios are unacceptably high, the situation is critical. In such situations, the delay may increase rapidly with small changes in demand. The full range of potential geometric and signal design changes should be considered in the search for improvements.

In summary, unacceptable delay can exist when capacity is a problem as well as when capacity is adequate. Further, acceptable delay levels do not automatically ensure that capacity is sufficient. Delay and capacity are complex variables that are influenced by a wide range of traffic, roadway, and signalization conditions. The methodology presented here can be used to estimate these performance measures, identify possible problems, and assist in developing alternative improvements.

PEDESTRIAN MODE

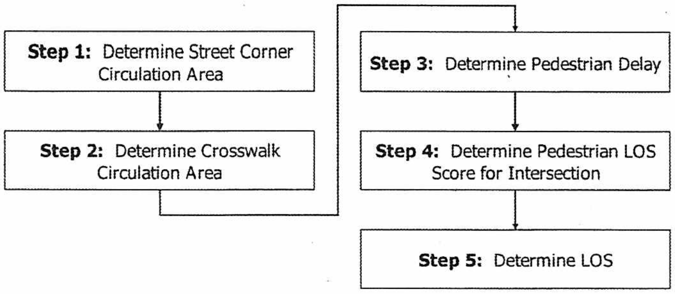
This subsection describes the methodology for evaluating the performance of a signalized intersection in terms of its service to pedestrians.

Intersection performance is separately evaluated for each crosswalk and intersection corner with this methodology. *Unless otherwise stated, all variables identified in this subsection are specific to one crosswalk and one corner.* A crosswalk is assumed to exist across each intersection leg unless crossing is specifically prohibited by local ordinance (and signed to this effect).

The methodology is focused on the analysis of signalized intersection performance. Chapter 17, Urban Street Segments, and Chapter 19, Two-Way STOP-Controlled Intersections, describe methodologies for evaluating the performance of these system elements with respect to the pedestrian mode.

The pedestrian methodology is applied through a series of five steps that determine the pedestrian LOS for a crosswalk and associated corners. These steps are illustrated in Exhibit 18-23.

Exhibit 18-23
Pedestrian Methodology for Signalized Intersections



Step 1: Determine Street Corner Circulation Area
Step 2: Determine Crosswalk Circulation Area
Step 3: Determine Pedestrian Delay
Step 4: Determine Pedestrian LOS Score for Intersection
Step 5: Determine LOS

Concepts

Performance Measures

The methodology provides a variety of measures for evaluating intersection performance in terms of its service to pedestrians. Each measure describes a different aspect of the pedestrian trip through the intersection. Performance measures that are estimated include the following:

- Corner circulation area,
- Crosswalk circulation area,
- Pedestrian delay, and
- Pedestrian LOS score.

The first two performance measures listed are based on the concept of "circulation area." One measure is used to evaluate the circulation area provided to pedestrians while they wait at the corner. Another measure is used to evaluate the area provided while the pedestrian is crossing in the crosswalk. Circulation area describes the space available to the average pedestrian. A larger area is more desirable from the pedestrian perspective. Exhibit 18-24 can be used to evaluate intersection performance from a circulation-area perspective.

Exhibit 18-24
Qualitative Description of Pedestrian Space

Pedestrian Space (ft^2/p)	Description
>60	Ability to move in desired path, no need to alter movements
>40–60	Occasional need to adjust path to avoid conflicts
>24–40	Frequent need to adjust path to avoid conflicts
>15–24	Speed and ability to pass slower pedestrians restricted
>8–15	Speed restricted, very limited ability to pass slower pedestrians
≤8	Speed severely restricted, frequent contact with other users

Pedestrian delay represents the average time a pedestrian waits for a legal opportunity to cross an intersection leg. The LOS score is an indication of the typical pedestrian's perception of the overall crossing experience.

Flow Conditions

Exhibit 18-25 and Exhibit 18-26 show the variables considered when one corner and its two crosswalks are evaluated. Two flow conditions are illustrated.

Condition 1 corresponds to the minor-street crossing that occurs during the major-street through phase. The pedestrians who desire to cross the major street must wait at the corner. Condition 2 corresponds to the major-street crossing that occurs during the minor-street through phase. For this condition, the pedestrians who desire to cross the minor street wait at the corner.

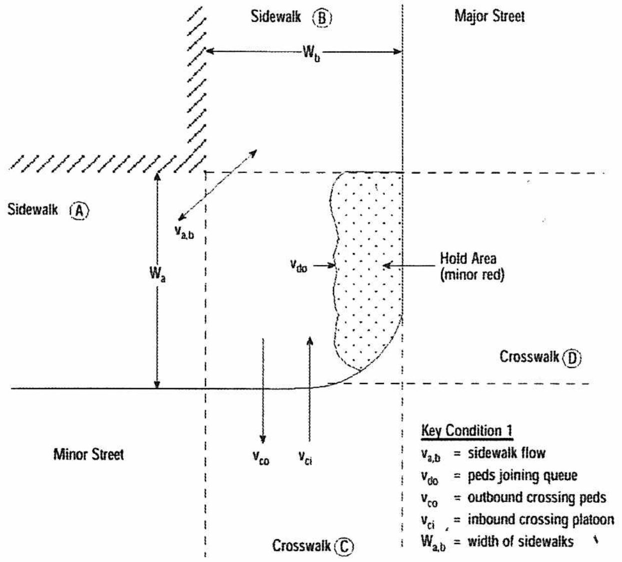

Sidewalk Ⓑ
Major Street
W_b
Sidewalk Ⓐ
$v_{a,b}$
W_a
v_{do}
Hold Area
(minor red)
Crosswalk Ⓓ
Minor Street
v_{co}
v_{ci}
Crosswalk Ⓒ
Key Condition 1
$v_{a,b}$ = sidewalk flow
v_{do} = peds joining queue
v_{co} = outbound crossing peds
v_{ci} = inbound crossing platoon
$W_{a,b}$ = width of sidewalks

Exhibit 18-25
Condition 1: Minor-Street Crossing

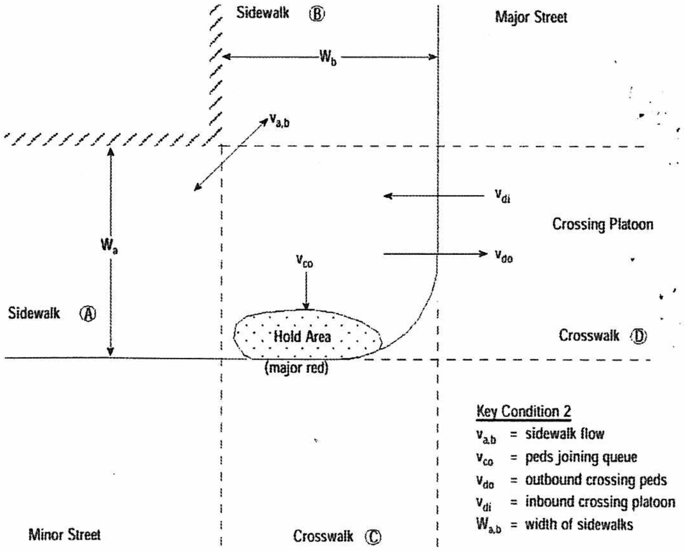


Exhibit 18-26
Condition 2: Major-Street Crossing

Effective Walk Time

Research indicates that, at intersections with pedestrian signal heads, pedestrians typically continue to enter the intersection during the first few seconds of the pedestrian clear interval (*26, 28*). This behavior effectively increases the effective walk time available to pedestrians. A conservative estimate of this additional walk time is 4.0 s (*26*). A nonzero value for this additional time implies that some pedestrians are initiating their crossing during the flashing DON'T WALK indication.

The following guidance is provided to estimate the effective walk time on the basis of the aforementioned research findings. If the phase providing service to the pedestrians is either (*a*) actuated with a pedestrian signal head and rest-in-walk *not* enabled or (*b*) pretimed with a pedestrian signal head, then

Equation 18-49

$$g_{\text{Walk}} = Walk + 4.0$$

If the phase providing service to the pedestrians is actuated with a pedestrian signal head and rest-in-walk enabled, then

Equation 18-50

$$g_{\text{Walk}} = D_p - Y - R_c - PC + 4.0$$

Otherwise (i.e., no pedestrian signal head)

Equation 18-51

$$g_{\text{Walk}} = D_p - Y - R_c$$

where

g_{Walk} = effective walk time (s),
$Walk$ = pedestrian walk setting (s),
PC = pedestrian clear setting (s),
D_p = phase duration (s),
Y = yellow change interval (s), and
R_c = red clearance interval (s).

The aforementioned research indicates that the effective walk time estimated with Equation 18-49 or Equation 18-50 can vary widely among intersections. At a given intersection, the additional walk time can vary from 0.0 s to an amount equal to the pedestrian clear interval. The amount of additional walk time used by pedestrians depends on many factors, including the extent of pedestrian delay, vehicular volume, level of enforcement, and presence of countdown pedestrian signal heads.

The effective walk time estimated with Equation 18-49 or Equation 18-50 is considered to be directly applicable to design or planning analyses because it is conservative in the amount of additional walk time that it includes. A larger value of effective walk time may be applicable to an operational analysis if (*a*) field observation or experience indicates such a value would be consistent with actual pedestrian use of the flashing DON'T WALK indication; (*b*) an accurate estimate of pedestrian delay or queue size is desired; and (*c*) the predicted performance estimates are understood to reflect some illegal pedestrian behavior, possibly in response to constrained spaces or inadequate signal timing.

Step 1: Determine Street Corner Circulation Area

This step describes a procedure for evaluating the performance of one intersection corner. It is repeated for each intersection corner of interest.

The analysis of circulation area at the street corners and in the crosswalks compares available time and space with pedestrian demand. The product of time and space is the critical parameter. It combines the constraints of physical design (which limits available space) and signal operation (which limits available time). This parameter is hereafter referred to as "time–space."

A. Compute Available Time–Space

The total time–space available for circulation and queuing in the intersection corner equals the product of the net corner area and the cycle length C. Equation 18-52 is used to compute time–space available at an intersection corner. Exhibit 18-10 identifies the variables used in the equation.

Equation 18-52

$$TS_{corner} = C\,(W_a W_b - 0.215\,R^2)$$

where

TS_{corner} = available corner time–space (ft²-s),

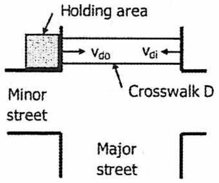
C = cycle length (s),

W_a = total walkway width of Sidewalk A (ft),

W_b = total walkway width of Sidewalk B (ft), and

R = radius of corner curb (ft).

If the corner curb radius is larger than either W_a or W_b, then the variable R in Equation 18-52 should equal the smaller of W_a or W_b.



B. Compute Holding-Area Waiting Time

The average pedestrian holding time represents the average time that pedestrians wait to cross the street when departing from the subject corner. The equation for computing this time is based on the assumption that pedestrian arrivals are uniformly distributed during the cycle. For Condition 1, as shown in Exhibit 18-25, Equation 18-53 and Equation 18-54 are used to compute holding-area time for pedestrians waiting to cross the major street.

Equation 18-53

$$Q_{tdo} = \frac{N_{do}(C - g_{\text{Walk},mi})^2}{2C}$$

with

Equation 18-54

$$N_{do} = \frac{v_{do}}{3{,}600}\,C$$

where

Q_{tdo} = total time spent by pedestrians waiting to cross the major street during one cycle (p-s),

N_{do} = number of pedestrians arriving at the corner each cycle to cross the major street (p),

$g_{\text{Walk},mi}$ = effective walk time for the phase serving the minor-street through movement (s),

C = cycle length (s), and

v_{do} = flow rate of pedestrians arriving at the corner to cross the major street (p/h).

If the phase providing service to the pedestrians is either (*a*) actuated with a pedestrian signal head and rest-in-walk *not* enabled or (*b*) pretimed with a pedestrian signal head, then

Equation 18-55

$$g_{\text{Walk},mi} = Walk_{mi} + 4.0$$

If the phase providing service to the pedestrians is actuated with a pedestrian signal head and rest-in-walk enabled, then

Equation 18-56

$$g_{\text{Walk},mi} = D_{p,mi} - Y_{mi} - R_{c,mi} - PC_{mi} + 4.0$$

Otherwise (i.e., no pedestrian signal head)

Equation 18-57

$$g_{\text{Walk},mi} = D_{p,mi} - Y_{mi} - R_{c,mi}$$

where

$g_{\text{Walk},mi}$ = effective walk time for the phase serving the minor-street through movement (s),

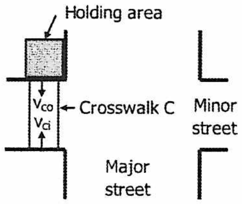
$Walk_{mi}$ = pedestrian walk setting for the phase serving the minor-street through movement (s),

PC_{mi} = pedestrian clear setting for the phase serving the minor-street through movement (s),

$D_{p,mi}$ = duration of the phase serving the minor-street through movement (s),

Y_{mi} = yellow change interval of the phase serving the minor-street through movement (s), and

$R_{c,mi}$ = red clearance interval of the phase serving the minor-street through movement (s).



For Condition 2, the previous three equations are repeated to compute the holding-area time for pedestrians waiting to cross the minor street Q_{tco}. For this application, the subscript letters "*do*" are replaced with the letters "*co*" to denote the pedestrians arriving at the corner to cross in Crosswalk C. Similarly, the subscript letters "*mi*" are replaced with "*mj*" to denote signal timing variables associated with the phase serving the major-street through movement.

C. Compute Circulation Time–Space

The time–space available for circulating pedestrians equals the total available time–space minus the time–space occupied by the pedestrians waiting to cross. The latter value equals the product of the total waiting time and the area used by waiting pedestrians (= 5.0 ft²/p). Equation 18-58 is used to compute the time–space available for circulating pedestrians.

Equation 18-58

$$TS_c = TS_{corner} - \left[5.0\,(Q_{tdo} + Q_{tco})\right]$$

where TS_c is the time–space available for circulating pedestrians (ft²-s) and other variables are as previously defined.

D. Compute Pedestrian Corner Circulation Area

The space required for circulating pedestrians is computed by dividing the time–space available for circulating pedestrians by the time that pedestrians consume walking through the corner area. The latter quantity equals the total circulation volume multiplied by the assumed average circulation time (= 4.0 s). Equation 18-59, with Equation 18-60, is used to compute corner circulation area.

Equation 18-59

$$M_{\text{corner}} = \frac{TS_c}{4.0\, N_{tot}}$$

with

Equation 18-60

$$N_{tot} = \frac{v_{ci} + v_{co} + v_{di} + v_{do} + v_{a,b}}{3{,}600}\, C$$

where

M_{corner} = corner circulation area per pedestrian (ft²/p),

N_{tot} = total number of circulating pedestrians that arrive each cycle (p),

v_{ci} = flow rate of pedestrians arriving at the corner after crossing the minor street (p/h),

v_{co} = flow rate of pedestrians arriving at the corner to cross the minor street (p/h),

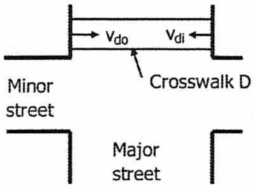
v_{di} = flow rate of pedestrians arriving at the corner after crossing the major street (p/h), and

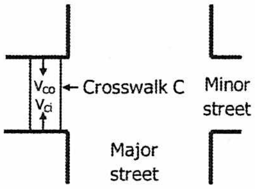
$v_{a,b}$ = flow rate of pedestrians traveling through the corner from Sidewalk A to Sidewalk B, or vice versa (p/h).

Other variables are as previously defined. The circulation area obtained from Equation 18-59 can be compared with the ranges provided in Exhibit 18-24 to make some judgments about the performance of the subject intersection corner.

Step 2: Determine Crosswalk Circulation Area

This step describes a procedure for evaluating the performance of one crosswalk. It is repeated for each crosswalk of interest.





The procedure to follow describes the evaluation of Crosswalk D in Exhibit 18-26 (i.e., a crosswalk across the major street). The procedure is repeated to evaluate Crosswalk C in Exhibit 18-25. For the second application, the subscript letters "*do*" and "*di*" are replaced with the letters "*co*" and "*ci*," respectively, to denote the pedestrians associated with Crosswalk C. Similarly, the subscript letter "*d*" is replaced with the letter "*c*" to denote the length and width of Crosswalk C. Also, the subscript letters "*mi*" are replaced with "*mj*" to denote signal timing variables associated with the phase serving the major-street through movement.

A. Establish Walking Speed

The recommended walking speeds reflect average (50th percentile) walking speeds for the purposes of calculating LOS. Traffic signal timing for pedestrians is typically based on a 15th percentile walking speed.

The average pedestrian walking speed S_p is needed to evaluate corner and crosswalk performance. Research indicates that the walking speed is influenced by pedestrian age and sidewalk grade (26). If 0% to 20% of pedestrians traveling along the subject segment are elderly (i.e., 65 years of age or older), an average walking speed of 4.0 ft/s is recommended for intersection evaluation. If more than 20% of all pedestrians are elderly, an average walking speed of 3.3 ft/s is recommended. In addition, an upgrade of 10% or greater reduces walking speed by 0.3 ft/s.

B. Compute Available Time–Space

Equation 18-61 is used to compute the time–space available in the crosswalk.

Equation 18-61

$$TS_{cw} = L_d W_d \, g_{\text{Walk},mi}$$

where

TS_{cw} = available crosswalk time–space (ft²-s),

L_d = length of Crosswalk D (ft),

W_d = effective width of Crosswalk D (ft), and

$g_{\text{Walk},mi}$ = effective walk time for the phase serving the minor-street through movement (s).

C. Compute Effective Available Time–Space

The available crosswalk time–space is adjusted in this step to account for the effect turning vehicles have on pedestrians. This adjustment is based on the assumed occupancy of a vehicle in the crosswalk. The vehicle occupancy is computed as the product of vehicle swept-path, crosswalk width, and the time the vehicle preempts this space. Equation 18-62 through Equation 18-64 are used for this purpose.

Equation 18-62

$$TS^{*}_{cw} = TS_{cw} - TS_{tv}$$

with

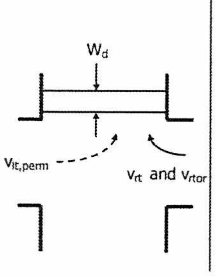
Equation 18-63

$$TS_{tv} = 40\, N_{tv} W_d$$

Equation 18-64

$$N_{tv} = \frac{v_{lt,perm} + v_{rt} - v_{rtor}}{3{,}600} C$$

where



TS_{cw}^{*} = effective available crosswalk time–space (ft²-s),

TS_{tv} = time–space occupied by turning vehicles (ft²-s),

N_{tv} = number of turning vehicles during the walk and pedestrian clear intervals (veh),

$v_{lt,perm}$ = permitted left-turn demand flow rate (veh/h),

v_{rt} = right-turn demand flow rate (veh/h), and

v_{rtor} = right-turn-on-red flow rate (veh/h).

Other variables are as previously defined. The constant 40 in Equation 18-63 represents the product of the swept-path for most vehicles (= 8 ft) and the time that a turning vehicle occupies the crosswalk (= 5 s). The left-turn and right-turn flow rates used in Equation 18-64 are those associated with movements that receive a green indication concurrently with the subject pedestrian crossing *and* turn across the subject crosswalk.

D. Compute Pedestrian Service Time

Total service time is computed with either Equation 18-65 or Equation 18-66, depending on the crosswalk width, along with Equation 18-67. This time represents the elapsed time starting with the first pedestrian's departure from the corner to the last pedestrian's arrival at the far side of the crosswalk. In this manner, it accounts for platoon size in the service time (*29*).

If crosswalk width W_d is greater than 10 ft, then

$$t_{ps,do} = 3.2 + \frac{L_d}{S_p} + 2.7\frac{N_{ped,do}}{W_d}$$

Equation 18-65

If crosswalk width W_d is less than or equal to 10 ft, then

$$t_{ps,do} = 3.2 + \frac{L_d}{S_p} + 0.27\, N_{ped,do}$$

Equation 18-66

with

$$N_{ped,do} = N_{do}\frac{C - g_{\text{Walk},mi}}{C}$$

Equation 18-67

where

$t_{ps,do}$ = service time for pedestrians that arrive at the corner to cross the major street (s),

$N_{ped,do}$ = number of pedestrians waiting at the corner to cross the major street (p), and

other variables are as previously defined.

Equation 18-67 provides an estimate of the number of pedestrians who cross as a group following the presentation of the WALK indication (or green indication, if pedestrian signal heads are not provided). It is also used to compute $N_{ped,di}$ for the other travel direction in the same crosswalk (using N_{di}, as defined below). Finally, Equation 18-65 or Equation 18-66 is used to compute the service time for pedestrians who arrive at the subject corner having waited on the other corner before crossing the major street $t_{ps,di}$ (using $N_{ped,di}$).

E. Compute Crosswalk Occupancy Time

The total crosswalk occupancy time is computed as a product of the pedestrian service time and the number of pedestrians using the crosswalk during one signal cycle. Equation 18-68 is used, with Equation 18-69 and results from previous steps, for the computation.

Equation 18-68

$$T_{occ} = t_{ps,do} N_{do} + t_{ps,di} N_{di}$$

with

Equation 18-69

$$N_{di} = \frac{v_{di}}{3{,}600} C$$

where

T_{occ} = crosswalk occupancy time (p-s), and

N_{di} = number of pedestrians arriving at the corner each cycle having crossed the major street (p).

Other variables are as previously defined.

F. Compute Pedestrian Crosswalk Circulation Area

The circulation space provided for each pedestrian is determined by dividing the time–space available for crossing by the total occupancy time, as shown in Equation 18-70.

Equation 18-70

$$M_{cw} = \frac{TS^{*}_{cw}}{T_{occ}}$$

where M_{cw} is the crosswalk circulation area per pedestrian (ft²/p) and other variables are as previously defined.

The circulation area obtained from Equation 18-70 can be compared with the ranges provided in Exhibit 18-24 to make some judgments about the performance of the subject-intersection crosswalk (for the specified direction of travel). For a complete picture of the subject crosswalk's performance, the procedure described in this step should be repeated for the other direction of travel along the crosswalk (i.e., by using the other corner associated with the crosswalk as the point of reference).

Step 3: Determine Pedestrian Delay

This step describes a procedure for evaluating the performance of a crosswalk at the intersection. It is repeated for each crosswalk of interest.

The discussion that follows describes the evaluation of Crosswalk D shown in Exhibit 18-26. The procedure is applied again to evaluate Crosswalk C shown in Exhibit 18-25. For the second application, the subscript letters "*mi*" are replaced with "*mj*" to denote signal timing variables associated with the phase serving the major-street through movement.

The pedestrian delay while waiting to cross the major street is computed with Equation 18-71.

Equation 18-71

$$d_p = \frac{(C - g_{\text{Walk},mi})^2}{2C}$$

where d_p is pedestrian delay (s/p) and other variables are as previously defined.

The delay obtained from Equation 18-71 applies equally to both directions of travel along the crosswalk.

$$\frac{0\cdot g + \frac{c-g}{2}\cdot(c-g)}{c}$$

$$\frac{(c-g)^2}{2c}$$

average from c to c-g

$$\frac{\left(c-\frac{g}{2}\right)\cdot g + \frac{c-g}{2}\cdot(c-g)}{c}$$

$$\frac{cg - \frac{g^2}{2} + \frac{(c-g)^2}{2}}{c}$$

Research indicates that average pedestrian delay at signalized intersection crossings is not constrained by capacity, even when pedestrian flow rates reach 5,000 p/h (*26*). For this reason, delay due to oversaturated conditions is not included in the value obtained from Equation 18-71.

If the subject crosswalk is closed, then the pedestrian delay d_p is estimated as the value obtained from Equation 18-71 for the subject crosswalk, plus two increments of the delay from this equation when applied to the perpendicular crosswalk. This adjustment reflects the additional delay pedestrians incur when crossing the other three legs of the intersection so that they can continue walking in the desired direction.

The pedestrian delay computed in this step can be used to make some judgment about pedestrian compliance. In general, pedestrians become impatient when they experience delays in excess of 30 s/p, and there is a high likelihood of their not complying with the signal indication (*30*). In contrast, pedestrians are very likely to comply with the signal indication if their expected delay is less than 10 s/p.

Step 4: Determine Pedestrian LOS Score for Intersection

This step describes a procedure for evaluating the performance of one crosswalk. It is repeated for each crosswalk of interest.

The procedure to follow describes the evaluation of Crosswalk D in Exhibit 18-26. The procedure is repeated to evaluate Crosswalk C in Exhibit 18-25. For the second application, the subscript letter "*d*" is replaced with the letter "*c*" to denote the length and width of Crosswalk C. Also, the subscript letters "*mj*" are replaced with "*mi*" to denote variables associated with the minor street.

The pedestrian LOS score for the intersection $I_{p,int}$ is calculated by using Equation 18-72 through Equation 18-77.

$$I_{p,int} = 0.5997 + F_w + F_v + F_S + F_{\text{delay}}$$

Equation 18-72

with

$$F_w = 0.681\left(N_d\right)^{0.514}$$

Equation 18-73

$$F_v = 0.00569\left(\frac{v_{rtor} + v_{lt,perm}}{4}\right) - N_{rtci,d}\left(0.0027\, n_{15,mj} - 0.1946\right)$$

Equation 18-74

$$F_S = 0.00013\, n_{15,mj}\, S_{85,mj}$$

Equation 18-75

$$F_{\text{delay}} = 0.0401\,\ln(d_{p,d})$$

Equation 18-76

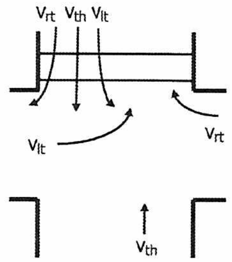
$$n_{15,mj} = \frac{0.25}{N_d}\sum_{i \in m_d} v_i$$

Equation 18-77

$$\frac{2cg - g^2 + (c-g)^2}{2c}$$

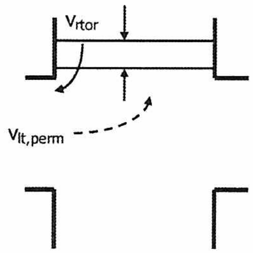
where

$I_{p,int}$ = pedestrian LOS score for intersection,
F_w = cross-section adjustment factor,
F_v = motorized vehicle volume adjustment factor,
F_S = motorized vehicle speed adjustment factor,
F_{delay} = pedestrian delay adjustment factor,
$\ln(x)$ = natural logarithm of x,
N_d = number of traffic lanes crossed when traversing Crosswalk D (ln),
$N_{rtci,d}$ = number of right-turn channelizing islands along Crosswalk D,
$n_{15,mj}$ = count of vehicles traveling on the major street during a 15-min period (veh/ln),
$S_{85,mj}$ = 85th percentile speed at a midsegment location on the major street (mi/h),
$d_{p,d}$ = pedestrian delay when traversing Crosswalk D (s/p),
v_i = demand flow rate for movement i (veh/h), and
m_d = set of all automobile movements that cross Crosswalk D (see figure in margin).



Movements crossing Crosswalk D

The left-turn flow rate $v_{lt,perm}$ used in Equation 18-74 is that associated with the left-turn movement that receives a green indication concurrently with the subject pedestrian crossing *and* turns across the subject crosswalk. The RTOR flow rate v_{rtor} is that associated with the approach being crossed and that turns across the subject crosswalk. It is not the same v_{rtor} used in Equation 18-64.



The pedestrian LOS score obtained from this equation applies equally to both directions of travel along the crosswalk.

The variable for "number of right-turn channelizing islands" N_{rtci} is an integer with a value of 0, 1, or 2.

Step 5: Determine LOS

This step describes a process for determining the LOS of one crosswalk. It is repeated for each crosswalk of interest.

The pedestrian LOS is determined by using the pedestrian LOS score from Step 4. This performance measure is compared with the thresholds in Exhibit 18-5 to determine the LOS for the subject crosswalk.

BICYCLE MODE

This subsection describes the methodology for evaluating the performance of a signalized intersection in terms of its service to bicyclists.

Intersection performance is evaluated separately for each intersection approach. *Unless otherwise stated, all variables identified in this subsection are specific to one intersection approach.* The bicycle is assumed to travel in the street (possibly in a bicycle lane) and in the same direction as adjacent motorized vehicles.

The methodology is focused on analyzing signalized intersection performance from the bicyclist point of view. Chapter 17, Urban Street Segments, describes a methodology for evaluating urban street performance.

The bicycle methodology is applied through a series of three steps that determine the bicycle LOS for an intersection approach. These steps are illustrated in Exhibit 18-27. Performance measures that are estimated include bicycle delay and a bicycle LOS score.

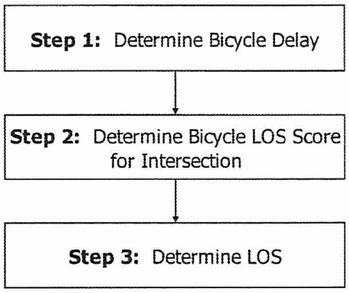

Step 1: Determine Bicycle Delay
Step 2: Determine Bicycle LOS Score for Intersection
Step 3: Determine LOS

Exhibit 18-27
Bicycle Methodology for Signalized Intersections

Step 1: Determine Bicycle Delay

This step describes a procedure for evaluating the performance of one intersection approach. It is repeated for each approach of interest. Bicycle delay can be calculated only for intersection approaches that have an on-street bicycle lane or a shoulder that can be used by bicyclists as a bicycle lane. Bicyclists who share a lane with automobile traffic will incur the same delay as the automobiles.

A. Compute Bicycle Lane Capacity

A wide range of capacities and saturation flow rates have been reported by many countries for bicycle lanes at intersections. Research indicates that the base saturation flow rate may be as high as 2,600 bicycles/h (*31*). However; few intersections provide base conditions for bicyclists, and current information is insufficient to calibrate a series of appropriate saturation flow adjustment factors. Until such factors are developed, it is recommended that a saturation flow rate of 2,000 bicycles/h be used as an average value achievable at most intersections.

A saturation flow rate of 2,000 bicycles/h assumes that right-turning motor vehicles yield the right-of-way to through bicyclists. Where aggressive right-turning traffic exists, 2,000 bicycles/h may not be achievable. Local observations to determine a saturation flow rate are recommended in such cases.

The capacity of the bicycle lane at a signalized intersection may be computed with Equation 18-78.

Equation 18-78

$$c_b = s_b \frac{g_b}{C}$$

where

c_b = capacity of the bicycle lane (bicycles/h),

s_b = saturation flow rate of the bicycle lane = 2,000 (bicycles/h),

g_b = effective green time for the bicycle lane (s), and

C = cycle length (s).

The effective green time for the bicycle lane can be assumed to equal that for the adjacent motor-vehicle traffic stream that is served concurrently with the subject bicycle lane (i.e., $g_b = D_p - l_1 - l_2$).

B. Compute Bicycle Delay

Bicycle delay is computed with Equation 18-79.

Equation 18-79

$$d_b = \frac{0.5\,C\,(1 - g_b / C)^2}{1 - \min\left[\frac{v_{bic}}{c_b}, 1.0\right]\frac{g_b}{C}}$$

where d_b is bicycle delay (s/bicycle), v_{bic} is bicycle flow rate (bicycles/h), and other variables are as previously defined.

This delay equation is based on the assumption that there is no bicycle incremental delay or initial queue delay. Bicyclists will not normally tolerate an oversaturated condition and will select other routes or ignore traffic regulations to avoid the associated delays.

At most signalized intersections, the only delay to through bicycles is caused by the signal, because bicycles have the right-of-way over right-turning vehicles during the green indication. Bicycle delay could be longer than that obtained from Equation 18-79 when (*a*) bicycles are forced to weave with right-turning traffic during the green indication, or (*b*) drivers do not acknowledge the bicycle right-of-way because of high flows of right-turning vehicles.

The delay obtained from Equation 18-79 can be used to make some judgment about intersection performance. Bicyclists tend to have about the same tolerance for delay as pedestrians. They tend to become impatient when they experience a delay in excess of 30 s/bicycle. In contrast, they are very likely to comply with the signal indication if their expected delay is less than 10 s/bicycle.

Step 2: Determine Bicycle LOS Score for Intersection

This step describes a procedure for evaluating the performance of one intersection approach. It is repeated for each approach of interest. The bicycle LOS score can be calculated for any intersection approach, regardless of whether it has an on-street bicycle lane.

The bicycle LOS score for the intersection $I_{b,int}$ is calculated by using Equation 18-80 through Equation 18-83.

Equation 18-80

$$I_{b,int} = 4.1324 + F_w + F_v$$

with

Equation 18-81

$$F_w = 0.0153\,W_{cd} - 0.2144\,W_t$$

Equation 18-82

$$F_v = 0.0066\,\frac{v_{lt} + v_{th} + v_{rt}}{4\,N_{th}}$$

$$W_t = W_{ol} + W_{bl} + I_{pk} W_{os}^*$$

Equation 18-83

where

$I_{b,int}$ = bicycle LOS score for intersection;

W_{cd} = curb-to-curb width of the cross street (ft);

W_t = total width of the outside through lane, bicycle lane, and paved shoulder (ft);

v_{lt} = left-turn demand flow rate (veh/h);

v_{th} = through demand flow rate (veh/h);

v_{rt} = right-turn demand flow rate (veh/h);

N_{th} = number of through lanes (shared or exclusive) (ln);

W_{ol} = width of the outside through lane (ft);

W_{bl} = width of the bicycle lane = 0.0 if bicycle lane not provided (ft);

I_{pk} = indicator variable for on-street parking occupancy = 0 if $p_{pk} > 0.0$, 1 otherwise;

p_{pk} = proportion of on-street parking occupied (decimal);

W_{os} = width of paved outside shoulder (ft); and

W_{os}^* = adjusted width of paved outside shoulder; if curb is present $W_{os}^* = W_{os} - 1.5 \geq 0.0$, otherwise $W_{os}^* = W_{os}$ (ft).

The variable "proportion of on-street parking occupied" is used to describe the presence of on-street parking and activity on the approach and departure legs of the intersection that are used by the subject bicycle movement.

Step 3: Determine LOS

This step describes a process for determining the LOS of one intersection approach. It is repeated for each approach of interest.

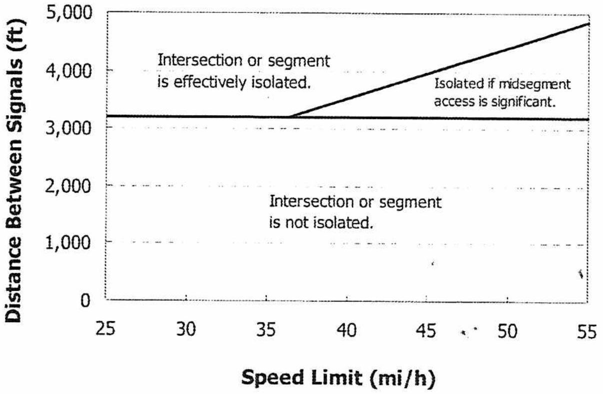
The bicycle LOS is determined by using the bicycle LOS score from Step 2. This performance measure is compared with the thresholds in Exhibit 18-5 to determine the LOS for the subject approach.

distance between signals is above the trend line, then the subject intersection or segment is likely to operate as effectively isolated (provided that it is not coordinated with the upstream signal).

LOS CRITERIA

This subsection describes the LOS criteria for the automobile, pedestrian, bicycle, and transit modes. The criteria for the automobile mode are different from the criteria used for the nonautomobile modes. Specifically, the automobile mode criteria are based on performance measures that are field-measurable and perceivable by travelers. The criteria for the pedestrian and bike modes are based on scores reported by travelers indicating their perception of service quality. The criteria for the transit mode are based on measured changes in transit patronage due to changes in service quality.

Exhibit 16-3
Signal Spacing Associated with Effectively Isolated Operation



Automobile Mode

All uses of the word "volume" or the phrase "volume-to-capacity ratio" in this chapter refer to demand volume or demand-volume-to-capacity ratio.

Through-vehicle travel speed is used to characterize vehicular LOS for a given direction of travel along an urban street facility. This speed reflects the factors that influence running time along each link and the delay incurred by through vehicles at each boundary intersection. This performance measure indicates the degree of mobility provided by the facility. The following paragraphs characterize each service level.

LOS A describes primarily free-flow operation. Vehicles are completely unimpeded in their ability to maneuver within the traffic stream. Control delay at the boundary intersections is minimal. The travel speed exceeds 85% of the base free-flow speed.

LOS B describes reasonably unimpeded operation. The ability to maneuver within the traffic stream is only slightly restricted and control delay at the boundary intersections is not significant. The travel speed is between 67% and 85% of the base free-flow speed.

LOS C describes stable operation. The ability to maneuver and change lanes at midsegment locations may be more restricted than at LOS B. Longer queues at the boundary intersections may contribute to lower travel speeds. The travel speed is between 50% and 67% of the base free-flow speed.

LOS D indicates a less stable condition in which small increases in flow may cause substantial increases in delay and decreases in travel speed. This operation may be due to adverse signal progression, high volume, or inappropriate signal timing at the boundary intersections. The travel speed is between 40% and 50% of the base free-flow speed.

LOS E is characterized by unstable operation and significant delay. Such operations may be due to some combination of adverse progression, high volume, and inappropriate signal timing at the boundary intersections. The travel speed is between 30% and 40% of the base free-flow speed.

LOS F is characterized by flow at extremely low speed. Congestion is likely occurring at the boundary intersections, as indicated by high delay and extensive queuing. The travel speed is 30% or less of the base free-flow speed. Also, LOS F is assigned to the subject direction of travel if the through movement at one or more boundary intersections has a volume-to-capacity ratio greater than 1.0.

Exhibit 16-4 lists the LOS thresholds established for the automobile mode on urban streets.

Exhibit 16-4
LOS Criteria: Automobile Mode

Travel Speed as a Percentage of Base Free-Flow Speed (%)	LOS by Critical Volume-to-Capacity Ratio[a]	
	≤ 1.0	> 1.0
>85	A	F
>67–85	B	F
>50–67	C	F
>40–50	D	F
>30–40	E	F
≤30	F	F

Note: [a] The critical volume-to-capacity ratio is based on consideration of the through movement volume-to-capacity ratio at each boundary intersection in the subject direction of travel. The critical volume-to-capacity ratio is the largest ratio of those considered.

Nonautomobile Modes

Historically, this manual has used a single performance measure as the basis for defining LOS. However, research documented in Chapter 5, Quality and Level-of-Service Concepts, indicates that travelers consider a wide variety of factors in assessing the quality of service provided to them. Some of these factors can be described as performance measures (e.g., speed), and others can be described as basic descriptors of the urban street character (e.g., sidewalk width). The methodologies in Chapter 17, Urban Street Segments, and Chapter 18, Signalized Intersections, provide procedures for mathematically combining these factors into a score for the segment or intersection, respectively. This score is then used in this chapter to determine the LOS that is provided for a given direction of travel along a facility.

Exhibit 16-5 lists the range of scores associated with each LOS for the pedestrian travel mode. The LOS for this particular mode is determined by consideration of both the LOS score and the average pedestrian space on the sidewalk. The applicable LOS for an evaluation is determined from the table by finding the intersection of the row corresponding to the computed score value and the column corresponding to the computed space value.

The association between LOS score and LOS is based on traveler perception research. Travelers were asked to rate the quality of service associated with a specific trip along an urban street. The letter "A" was used to represent the "best" quality of service, and the letter "F" was used to represent the "worst" quality of service. "Best" and "worst" were left undefined, allowing respondents to identify the best and worst conditions on the basis of their traveling experience and perception of service quality.

Exhibit 16-5
LOS Criteria: Pedestrian Mode

Pedestrian LOS Score	LOS by Average Pedestrian Space (ft^2/p)					
	>60	>40–60	>24–40	>15–24	>8.0–15[a]	≤ 8.0[a]
≤2.00	A	B	C	D	E	F
>2.00–2.75	B	B	C	D	E	F
>2.75–3.50	C	C	C	D	E	F
>3.50–4.25	D	D	D	D	E	F
>4.25–5.00	E	E	E	E	E	F
>5.00	F	F	F	F	F	F

Note: [a] In cross-flow situations, the LOS E–F threshold is 13 ft^2/p.

Exhibit 16-6 lists the range of scores that are associated with each LOS for the bicycle and transit modes. This exhibit is also applicable for determining pedestrian LOS when a sidewalk is not available.

Exhibit 16-6
LOS Criteria: Bicycle and Transit Modes

LOS	LOS Score
A	≤2.00
B	>2.00–2.75
C	>2.75–3.50
D	>3.50–4.25
E	>4.25–5.00
F	>5.00

REQUIRED INPUT DATA

This subsection describes the required input data for the automobile, pedestrian, bicycle, and transit methodologies.

Automobile Mode

This part describes the input data needed for the automobile methodology. The data are listed in Exhibit 16-7 and are identified as "input data elements." For the subject travel direction, these elements must be provided for each segment and for the through-movement group at each boundary intersection.

The last column in Exhibit 16-7 indicates whether the input data are needed for a movement group at a boundary intersection, the overall intersection, or the segment. The input data needed to evaluate the segment are identified in Chapter 17, Urban Street Segments. Similarly, the input data needed to evaluate the boundary intersections are identified in the appropriate chapter (i.e., Chapters 18 to 22).

Exhibit 16-7
Input Data Requirements: Automobile Mode

Data Category	Location	Input Data Element	Basis
Geometric Design	Segment	Segment length	Segment
Other	Segment	Analysis period duration	Facility
Performance Measures	Boundary intersection	Volume-to-capacity ratio	Through-movement group
	Segment	Base free-flow speed	Segment
		Travel speed	Segment

Notes: Through-movement group = one value for the segment through movement at the downstream boundary intersection (inclusive of any turn movements in a shared lane).
Segment = one value or condition for each segment and direction of travel on the facility.
Facility = one value or condition for the facility.

Segment Length

Segment length represents the distance between the boundary intersections that define the segment. The point of measurement at each intersection is the stop line, the yield line, or the functional equivalent in the subject direction of travel. This length is measured along the centerline of the street. If it differs in the two travel directions, then an average length is used. One length is needed for each segment on the facility.

Analysis Period Duration

The analysis period is the time interval considered for the performance evaluation. Its duration is in the range of 15 min to 1 h, with longer durations in this range sometimes used for planning analyses. In general, the analyst should use caution in interpreting the results from an analysis period of 1 h or more because the adverse impact of short peaks in traffic demand may not be detected. Also, if the analysis period is other than 15 min, then the peak hour factor should not be used.

The methodology was developed to evaluate conditions in which queue spillback does not affect the performance of a segment or a boundary intersection during the analysis period. If spillback affects performance, the analyst should consider using an alternative analysis tool that is able to model the effect of spillback conditions.

Operational Analysis. A 15-min analysis period should be used for operational analyses. This duration will accurately capture the adverse effects of demand peaks. Any 15-min period of interest can be evaluated with the methodology; however, a complete evaluation should always include an analysis of conditions during the 15-min period that experiences the highest traffic demand during a 24-h period.

If traffic demand exceeds capacity for a given 15-min analysis period, then a multiple-period analysis should be conducted. This type of analysis consists of an evaluation of several consecutive 15-min time periods. The periods analyzed would include an initial analysis period that has no initial queue, one or more periods in which demand exceeds capacity, and a final analysis period that has no residual queue.

When a multiple-period analysis is used, facility performance measures are computed for each analysis period. Averaging performance measures across multiple analysis periods is not encouraged because it may obscure extreme values.

If a multiple-period analysis is used and the boundary intersections are signalized, then the procedure described in Chapter 18 should be used to guide the evaluation. When a procedure for multiple-period analysis is not provided in the chapter that corresponds to the boundary intersection configuration, the analyst should separately evaluate each period and use the residual queue from one period as the initial queue for the next period.

Planning Analysis. A 15-min analysis period is used for most planning analyses. However, hourly traffic demands are normally produced through the planning process. Thus, when 15-min forecast demands are not available for a 15-min analysis period, a peak hour factor must be used to estimate the 15-min demands for the analysis period. A 1-h analysis period can be used, if appropriate. Regardless of analysis period duration, a single-period analysis is typical for planning applications.

Volume-to-Capacity Ratio

This volume-to-capacity ratio is for the lane group serving the through movement that exits the segment at the downstream boundary intersection. With one exception, a procedure for computing this ratio is described in the appropriate intersection chapter (i.e., Chapters 18 to 22). Chapter 19, Two-Way STOP-Controlled Intersections, does not provide a procedure for estimating the capacity of the uncontrolled through movement, but this capacity can be estimated by using Equation 16-1:

Equation 16-1

$$c_{th} = 1{,}800\,(N_{th} - 1 + p^{*}_{0,j})$$

where

c_{th} = through-movement capacity (veh/h),

N_{th} = number of through lanes (shared or exclusive) (ln), and

$p^{*}_{0,j}$ = probability that there will be no queue in the inside through lane.

The probability $p^{*}_{0,j}$ is computed by using Equation 19-43 in Chapter 19. It is equal to 1.0 if a left-turn bay is provided for left turns from the major street.

One volume-to-capacity ratio is needed for the downstream boundary intersection of each segment on the facility.

Base Free-Flow Speed

The base free-flow speed characterizes the traffic speed on the segment when free-flow conditions exist and speed is uninfluenced by signal spacing. A procedure for determining this speed is described in Chapter 17. One speed is needed for each travel direction on each segment on the facility.

Travel Speed

Travel speed represents the ratio of segment length to through-movement travel time. Travel time is computed as the sum of segment running time and through-movement control delay at the downstream boundary intersection. A procedure for computing travel speed is described in Chapter 17. One speed is needed for each travel direction of each segment on the facility.

Nonautomobile Modes

This part describes the input data needed for the pedestrian, bicycle, and transit methodologies. The data are listed in Exhibit 16-8 and are identified as "input data elements." They must be separately specified for each direction of travel on the facility. Segment length is defined in the previous part.

Exhibit 16-8 categorizes each input data element by travel mode methodology. An "X" is used to indicate the association between a data element and methodology. A blank cell indicates that the data element is not used as input for the corresponding methodology.

Exhibit 16-8
Input Data Requirements: Nonautomobile Modes

Data Category	Location	Input Data Element	Pedestrian Mode	Bicycle Mode	Transit Mode
Geometric Design	Segment	Segment length	X	X	X
		Presence of a sidewalk	X		
Performance Measures	Segment	Pedestrian space	X		
		Pedestrian travel speed	X		
		Pedestrian LOS score for segment	X		
		Bicycle travel speed		X	
		Bicycle LOS score for segment		X	
		Transit travel speed			X
		Transit LOS score for segment			X

Presence of a Sidewalk

A sidewalk is a paved walkway that is provided at the side of the roadway. It is assumed that pedestrians will walk in the street if a sidewalk is not present. An indication of sidewalk presence is needed for each side of interest for each segment on the facility.

Pedestrian Space

Pedestrian space is a performance measure that describes the average circulation area available to each pedestrian traveling along the sidewalk. A procedure is described in Chapter 17 for estimating this quantity for a given sidewalk. One value is needed for each sidewalk of interest associated with each segment on the facility.

Pedestrian Travel Speed

Pedestrian travel speed represents the ratio of segment length to pedestrian travel time. Travel time is computed as the sum of segment walking time and control delay at the downstream boundary intersection. A procedure for computing this travel speed is described in Chapter 17. One speed is needed for each sidewalk of interest associated with each segment on the facility.

Pedestrian LOS Score for Segment

The pedestrian LOS score for the segment is used in the pedestrian methodology to determine facility LOS. It is obtained from the pedestrian methodology in Chapter 17. One score is needed for each direction of travel of interest for each segment on the facility.

Bicycle Travel Speed

Bicycle travel speed represents the ratio of segment length to bicycle travel time. Travel time is computed as the sum of segment running time and control delay at the downstream boundary intersection. This speed is computed only when a bicycle lane is present on the segment. A procedure for computing this travel speed is described in Chapter 17. One speed is needed for each direction of travel of interest for each segment on the facility.

Bicycle LOS Score for Segment

The bicycle LOS score for the segment is used in the bicycle methodology to estimate facility LOS. It is obtained from the bicycle methodology in Chapter 17. One score is needed for each direction of travel of interest for each segment on the facility.

Transit Travel Speed

Transit travel speed represents the ratio of segment length to transit travel time. Travel time is computed as the sum of segment running time and control delay at the downstream boundary intersection. A procedure for computing this travel speed is described in Chapter 17. One speed is needed for each direction of travel of interest for each segment on the facility.

Transit LOS Score for Segment

The transit LOS score for the segment is used in the transit methodology to estimate facility LOS. It is obtained from the transit methodology in Chapter 17. One score is needed for each direction of travel of interest for each segment on the facility.

SCOPE OF THE METHODOLOGY

Four methodologies are presented in this chapter. One methodology is provided for each of the automobile, pedestrian, bicycle, and transit modes. This section identifies the conditions for which each methodology is applicable.

- **Signalized and two-way STOP-controlled boundary intersections.** All methodologies can be used to evaluate facility performance with signalized or two-way STOP-controlled boundary intersections. In the latter case, the cross street is STOP controlled. The automobile methodology can also be used to evaluate performance with all-way STOP- or YIELD-controlled (e.g., roundabout) boundary intersections.
- **Arterial and collector streets.** The four methodologies were developed with a focus on arterial and collector street conditions. If a methodology is used to evaluate a local street, then the performance estimates should be carefully reviewed for accuracy.
- **Steady flow conditions.** The four methodologies are based on the analysis of steady traffic conditions and, as such, are not well suited to the

evaluation of unsteady conditions (e.g., congestion, queue spillback, signal preemption).

- **Target road users.** Collectively, the four methodologies were developed to estimate the LOS perceived by automobile drivers, pedestrians, bicyclists, and transit passengers. They were not developed to provide an estimate of the LOS perceived by other road users (e.g., commercial vehicle drivers, automobile passengers, delivery truck drivers, or recreational vehicle drivers). However, it is likely that the perceptions of these other road users are reasonably well represented by the road users for whom the methodologies were developed.
- **Target travel modes.** The automobile methodology addresses mixed automobile, motorcycle, truck, and transit traffic streams in which the automobile represents the largest percentage of all vehicles. The pedestrian, bicycle, and transit methodologies address travel by walking, bicycle, and transit vehicle, respectively. The transit methodology is limited to the evaluation of public transit vehicles operating in mixed or exclusive traffic lanes and stopping along the street. The methodologies are not designed to evaluate the performance of other travel means (e.g., grade-separated rail transit, golf carts, or motorized bicycles).
- **Influences in the right-of-way.** A road user's perception of quality of service is influenced by many factors inside and outside of the urban street right-of-way. However, the methodologies in this chapter were specifically constructed to exclude factors that are outside of the right-of-way (e.g., buildings, parking lots, scenery, or landscaped yards) that might influence a traveler's perspective. This approach was followed because factors outside of the right-of-way are not under the direct control of the agency operating the street.
- **Mobility focus for automobile methodology.** The automobile methodology is intended to facilitate the evaluation of mobility. Accessibility to adjacent properties by way of automobile is not directly evaluated with this methodology. Regardless, a segment's accessibility should also be considered when its performance is evaluated, especially if the street is intended to provide such access. Oftentimes, factors that favor mobility reflect minimal levels of access and vice versa.
- **"Typical pedestrian" focus for pedestrian methodology.** The pedestrian methodology is not designed to reflect the perceptions of any particular pedestrian subgroup, such as pedestrians with disabilities. As such, the performance measures obtained from the methodology are not intended to be indicators of a sidewalk's compliance with U.S. Access Board guidelines related to the Americans with Disabilities Act requirements. For this reason, they should not be considered as a substitute for a formal compliance assessment of a pedestrian facility.

LIMITATIONS OF THE METHODOLOGY

The urban street facility methodology uses the performance measures estimated by the segment and intersection methodologies in Chapters 17 to 22. As such, it incorporates the limitations of these methodologies (which are identified in the respective segment or intersection chapter).

2. METHODOLOGY

OVERVIEW

This section describes four methodologies for evaluating the performance of an urban street facility. Each methodology addresses one possible travel mode within the street right-of-way. Analysts should choose the combination of methodologies that are appropriate for their analysis needs.

A complete evaluation of facility operation includes the separate examination of performance for all relevant travel modes for each travel direction. The performance measures associated with each mode and travel direction are assessed independently of one another. They are not mathematically combined into a single indicator of facility performance. This approach ensures that all performance impacts are considered on a mode-by-mode and direction-by-direction basis.

The focus of each methodology in this chapter is the facility. Methodologies for quantifying the performance of a segment or boundary intersection are described in other chapters (i.e., Chapters 17 to 22).

AUTOMOBILE MODE

This subsection provides an overview of the methodology for evaluating urban street facility performance from the motorist perspective. Each travel direction along the facility is separately evaluated. *Unless otherwise stated, all variables are specific to the subject direction of travel.*

The methodology is focused on the analysis of facilities with signalized, two-way STOP, all-way STOP, or roundabout boundary intersections. The signalized intersection can be an interchange ramp terminal.

Exhibit 16-9 illustrates the calculation framework of the automobile methodology. It identifies the sequence of calculations needed to estimate selected performance measures. The calculation process is shown to flow from top to bottom in the exhibit. The calculations are described more fully in the remainder of this subsection.

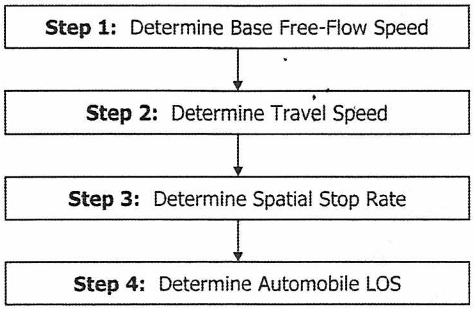

Step 1: Determine Base Free-Flow Speed
Step 2: Determine Travel Speed
Step 3: Determine Spatial Stop Rate
Step 4: Determine Automobile LOS

Exhibit 16-9
Automobile Methodology for Urban Street Facilities

Step 1: Determine Base Free-Flow Speed

The base free-flow speed for the facility is the basis for LOS determination. It is determined for each segment by using the procedures described in Chapter 17, Urban Street Segments. The base free-flow speed for the facility is calculated by using Equation 16-2:

Equation 16-2

$$S_{fo,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{fo,i}}}$$

where

$S_{fo,F}$ = base free-flow speed for the facility (mi/h),

L_i = length of segment i (ft),

m = number of segments on the facility, and

$S_{fo,i}$ = base free-flow speed for segment i (mi/h).

Step 2: Determine Travel Speed

The travel speed for the facility is the ratio of facility length to facility travel time. It represents an equivalent average speed for the through-vehicle traffic stream that reflects the running speed along the street for through vehicles and any delay they may incur at the boundary intersections. The travel speed for through vehicles is determined for each segment by using the procedures described in Chapter 17. The travel speed for the facility is calculated by using Equation 16-3:

Equation 16-3

$$S_{T,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{T,seg,i}}}$$

where $S_{T,F}$ is the travel speed for the facility (mi/h), $S_{T,seg,i}$ is the travel speed of through vehicles for segment i (mi/h), and other variables are as previously defined.

Step 3: Determine Spatial Stop Rate

The spatial stop rate for the facility is the ratio of stop count to facility length. It relates the number of full stops incurred by the average through vehicle to the distance traveled. The spatial stop rate for through vehicles is determined for each segment by using the procedures described in Chapter 17. The spatial stop rate for the facility is calculated by using Equation 16-4:

Equation 16-4

$$H_F = \frac{\sum_{i=1}^{m} H_{seg,i}\, L_i}{\sum_{i=1}^{m} L_i}$$

where H_F is the spatial stop rate for the facility (stops/mi), $H_{seg,i}$ is the spatial stop rate for segment i (stops/mi), and other variables are as previously defined.

The spatial stop rate from Equation 16-4 can be used to estimate an automobile traveler perception score for the facility if desired. The equations in Step 10 of Chapter 17 are used for this purpose. The value of H_F would be substituted for H_{seg} in each equation. Similarly, the proportion of intersections with a left-turn lane P_{LTL} would be calculated for the entire facility and this one value used in each equation.

Step 4: Determine Automobile LOS

LOS is determined for both directions of travel along the facility. Exhibit 16-4 lists the LOS thresholds established for this purpose. As indicated in this exhibit, LOS is defined by travel speed, expressed as a percentage of the base free-flow speed. The base free-flow speed is computed in Step 1 and the travel speed is computed in Step 2.

The footnote to Exhibit 16-4 indicates that volume-to-capacity ratio for the through movement at the downstream boundary intersections is also relevant to the determination of facility LOS. This footnote indicates that LOS F is assigned to the subject direction of travel if a volume-to-capacity ratio greater than 1.0 exists for the through movement at one or more boundary intersections.

Facility LOS must be interpreted with caution. It can suggest acceptable operation of the facility when, in reality, certain segments are operating at an unacceptable LOS. For each travel direction, the analyst should always verify that each segment is providing acceptable operation and consider reporting the LOS for the poorest-performing segment as a means of providing context for the interpretation of facility LOS.

PEDESTRIAN MODE

This subsection describes the methodology for evaluating the performance of an urban street facility in terms of its service to pedestrians.

Urban street facility performance from a pedestrian perspective is separately evaluated for each side of the street. *Unless otherwise stated, all variables identified in this section are specific to the subject side of the street.*

The methodology is focused on the analysis of facilities with either signal-controlled or two-way STOP-controlled boundary intersections. This edition of the HCM does not include a procedure for evaluating a facility's performance when a boundary intersection is an all-way STOP-controlled intersection, a roundabout, or a signalized interchange ramp terminal.

The pedestrian methodology is applied through a series of four steps that culminate in the determination of the facility LOS. These steps are illustrated in Exhibit 16-10.

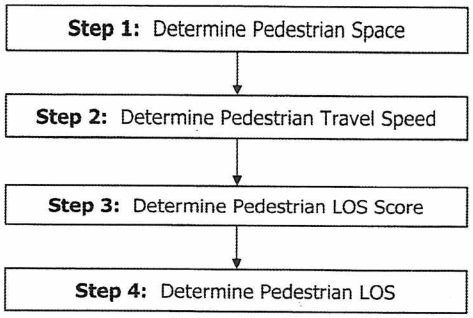

Step 1: Determine Pedestrian Space
Step 2: Determine Pedestrian Travel Speed
Step 3: Determine Pedestrian LOS Score
Step 4: Determine Pedestrian LOS

Exhibit 16-10
Pedestrian Methodology for Urban Street Facilities

Concepts

The methodology provides a variety of measures for evaluating facility performance in terms of its service to pedestrians. Each measure describes a different aspect of the pedestrian trip along the facility. One measure is the LOS score. This score is an indication of the typical pedestrian's perception of the overall facility travel experience. A second measure is the average speed of pedestrians traveling along the facility.

A third measure is based on the concept of "circulation area." It represents the average amount of sidewalk area available to each pedestrian walking along the facility. A larger area is more desirable from the pedestrian perspective. Exhibit 16-11 provides a qualitative description of pedestrian space that can be used to evaluate sidewalk performance from a circulation-area perspective.

Exhibit 16-11
Qualitative Description of Pedestrian Space

Pedestrian Space (ft^2/p)		
Random Flow	**Platoon Flow**	**Description**
>60	>530	Ability to move in desired path, no need to alter movements
>40–60	>90–530	Occasional need to adjust path to avoid conflicts
>24–40	>40–90	Frequent need to adjust path to avoid conflicts
>15–24	>23–40	Speed and ability to pass slower pedestrians restricted
>8–15	>11–23	Speed restricted, very limited ability to pass slower pedestrians
≤ 8	≤ 11	Speed severely restricted, frequent contact with other users

The first two columns in Exhibit 16-11 indicate a sensitivity to flow condition. Random pedestrian flow is typical of most facilities. Platoon flow is appropriate for facilities made up of shorter segments (e.g., in downtown areas) with signalized boundary intersections.

Step 1: Determine Pedestrian Space

Pedestrians are sensitive to the amount of space separating them from other pedestrians and obstacles as they walk along a sidewalk. Average pedestrian space is an indicator of facility performance for travel in a sidewalk. This step is applicable only when the sidewalk exists on the subject side of the street.

The pedestrian space is determined for each segment by using the procedures described in Chapter 17, Urban Street Segments. The pedestrian space for the facility is calculated by using Equation 16-5:

Equation 16-5

$$A_{p,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{A_{p,i}}}$$

where

$A_{p,F}$ = pedestrian space for the facility (ft²/p),

L_i = length of segment i (ft),

m = number of segments on the facility, and

$A_{p,i}$ = pedestrian space for segment i (ft²/p).

The pedestrian space for the facility reflects the space provided on the sidewalk along the segment. It does not consider the corner circulation area or the crosswalk circulation area at the intersections. Regardless, the analyst should verify that the intersection corners and crosswalks adequately accommodate pedestrians.

Step 2: Determine Pedestrian Travel Speed

The travel speed for the facility is the ratio of facility length to facility travel time. It represents an equivalent average speed of pedestrians that reflects their walking speed along the sidewalk and any delay they may incur at the boundary intersections. The travel speed for pedestrians is determined for each segment by using the procedures described in Chapter 17. The pedestrian travel speed for the facility is calculated by using Equation 16-6:

Equation 16-6

$$S_{Tp,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{Tp,seg,i}}}$$

where $S_{Tp,F}$ is the travel speed of through pedestrians for the facility (ft/s), $S_{Tp,seg,i}$ is the travel speed of through pedestrians for segment i (ft/s), and other variables are as previously defined.

In general, a travel speed of 4.0 ft/s or more is considered desirable, and a speed of 2.0 ft/s or less is considered undesirable.

Step 3: Determine Pedestrian LOS Score

The pedestrian LOS score for the facility is computed in this step. It represents a length-weighted average of the pedestrian LOS scores for the individual segments that make up the facility. The segment scores are determined by using the procedures described in Chapter 17. The score for the facility is calculated by using Equation 16-7:

$$I_{p,F} = \frac{\sum_{i=1}^{m} I_{p,seg,i}\, L_i}{\sum_{i=1}^{m} L_i}$$

Equation 16-7

where

$I_{p,F}$ = pedestrian LOS score for the facility, and

$I_{p,seg,i}$ = pedestrian LOS score for segment i.

Other variables are as previously defined.

Step 4: Determine Pedestrian LOS

The pedestrian LOS for the facility is determined by using the pedestrian LOS score from Step 3 and the average pedestrian space from Step 1. These two performance measures are compared with their respective thresholds in Exhibit 16-5 to determine the LOS for the specified direction of travel along the subject facility. If the sidewalk does not exist and pedestrians are relegated to walking in the street, then LOS is determined by using Exhibit 16-6 because the pedestrian space concept does not apply.

Facility LOS must be interpreted with caution. It can suggest acceptable operation of the facility when, in reality, certain segments are operating at an unacceptable LOS. For each travel direction, the analyst should always verify that each segment is providing acceptable operation and consider reporting the LOS for the poorest-performing segment as a means of providing context for the interpretation of facility LOS.

BICYCLE MODE

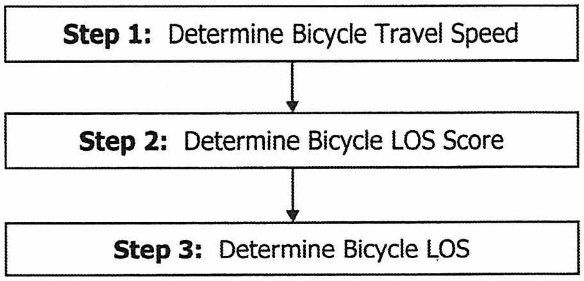
This subsection describes the methodology for evaluating the performance of an urban street facility in terms of its service to bicyclists.

Urban street facility performance from a bicyclist perspective is separately evaluated for each travel direction along the street. *Unless otherwise stated, all variables identified in this section are specific to the subject direction of travel.*

The methodology is focused on the analysis of a facility with either signal-controlled or two-way STOP-controlled boundary intersections. This edition of the HCM does not include a procedure for evaluating a facility's performance when a boundary intersection is an all-way STOP-controlled intersection, a roundabout, or a signalized interchange ramp terminal.

The bicycle methodology is applied through a series of three steps that culminate in the determination of the facility LOS. These steps are illustrated in Exhibit 16-12.

Exhibit 16-12
Bicycle Methodology for Urban Street Facilities


Step 1: Determine Bicycle Travel Speed
Step 2: Determine Bicycle LOS Score
Step 3: Determine Bicycle LOS

Step 1: Determine Bicycle Travel Speed

The travel speed for the facility is the ratio of facility length to facility travel time. It represents an equivalent average speed of bicycles that reflects their running speed along the street and any delay they may incur at the boundary intersections. The travel speed for bicycles is determined for each segment by using the procedures described in Chapter 17. The bicycle travel speed for the facility is calculated by using Equation 16-8:

Equation 16-8

$$S_{Tb,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{Tb,seg,i}}}$$

where

$S_{Tb,F}$ = travel speed of through bicycles for the facility (mi/h),

L_i = length of segment i (ft),

m = number of segments on the facility, and

$S_{Tb,seg,i}$ = travel speed of through bicycles for segment i (mi/h).

Step 2: Determine Bicycle LOS Score

The bicycle LOS score for the facility is computed in this step. It represents a length-weighted average of the bicycle LOS scores for the individual segments that make up the facility. The segment scores are determined by using the procedures described in Chapter 17. The score for the facility is calculated by using Equation 16-9:

Equation 16-9

$$I_{b,F} = \frac{\sum_{i=1}^{m} I_{b,seg,i}\, L_i}{\sum_{i=1}^{m} L_i}$$

where $I_{b,F}$ is the bicycle LOS score for the facility, $I_{b,seg,i}$ is the bicycle LOS score for segment i, and other variables are as previously defined.

Step 3: Determine Bicycle LOS

The bicycle LOS for the facility is determined by using the bicycle LOS score from Step 2. This performance measure is compared with the thresholds in Exhibit 16-6 to determine the LOS for the specified direction of travel along the subject facility.

Facility LOS must be interpreted with caution. It can suggest acceptable operation of the facility when, in reality, certain segments are operating at an unacceptable LOS. For each travel direction, the analyst should always verify that each segment is providing acceptable operation and consider reporting the LOS for the poorest-performing segment as a means of providing context for the interpretation of facility LOS.

TRANSIT MODE

This subsection describes the methodology for evaluating the performance of an urban street facility in terms of its service to transit passengers.

Urban street facility performance from a transit passenger perspective is separately evaluated for each travel direction along the street. *Unless otherwise stated, all variables identified in this section are specific to the subject direction of travel.*

The methodology is applicable to public transit vehicles operating in mixed traffic or exclusive lanes and stopping along the street. Procedures for estimating transit vehicle performance on grade-separated or non-public-street rights-of-way, along with procedures for estimating origin–destination service quality, are provided in the *Transit Capacity and Quality of Service Manual* (3).

The transit methodology is applied through a series of three steps that culminate in the determination of facility LOS. These steps are illustrated in Exhibit 16-13. If multiple routes exist on the segment, then each route is evaluated by using a separate application of this methodology.

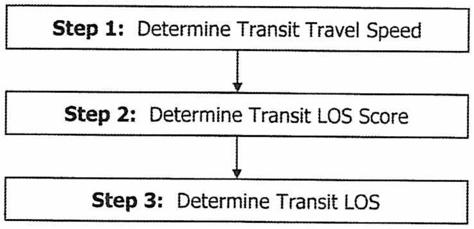

Step 1: Determine Transit Travel Speed
Step 2: Determine Transit LOS Score
Step 3: Determine Transit LOS

Exhibit 16-13
Transit Methodology for Urban Street Facilities

Step 1: Determine Transit Travel Speed

The travel speed for the facility is the ratio of facility length to facility travel time. It represents an equivalent average speed of transit vehicles that reflects their running speed along the street and any delay they may incur at the boundary intersection. The travel speed for a transit vehicle is determined for each segment by using the procedures described in Chapter 17. The transit travel speed for the facility is calculated by using Equation 16-10:

Equation 16-10

$$S_{Tt,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{Tt,seg,i}}}$$

where

$S_{Tt,F}$ = travel speed of transit vehicles for the facility (mi/h),

L_i = length of segment i (ft),

m = number of segments on the facility, and

$S_{Tt,seg,i}$ = travel speed of transit vehicles for segment i (mi/h).

Step 2: Determine Transit LOS Score

The transit LOS score for the facility is computed in this step. It represents a length-weighted average of the transit LOS score for the individual segments that make up the facility. The segment scores are determined by using the procedures described in Chapter 17. The score for the facility is calculated by using Equation 16-11:

Equation 16-11

$$I_{t,F} = \frac{\sum_{i=1}^{m} I_{t,seg,i}\, L_i}{\sum_{i=1}^{m} L_i}$$

where $I_{t,F}$ is the transit LOS score for the facility, $I_{t,seg,i}$ is the transit LOS score for segment i, and other variables are as previously defined.

Step 3: Determine Transit LOS

The transit LOS for the facility is determined by using the transit LOS score from Step 2. This performance measure is compared with the thresholds in Exhibit 16-6 to determine the LOS for the specified direction of travel along the subject facility.

Facility LOS must be interpreted with caution. It can suggest acceptable operation of the facility when, in reality, certain segments are operating at an unacceptable LOS. For each travel direction, the analyst should always verify that each segment is providing acceptable operation and consider reporting the LOS for the poorest-performing segment as a means of providing context for the interpretation of facility LOS.